Changes in POPCORN KERNELS AND COBS While Maturing

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CHANGES IN POPCORN KERNELS AND COBS WHILE MATURING

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VARIETY, moisture content at time of popping, and maturity or morphological and physiological development of popcorn when harvested are three of the principal factors governing popping expansion. The influence of the first two factors has received considerable attention, and their relative importance is fairly well understood. The third factor, maturation, has received little attention, and a number of interpretations exist concerning the time to harvest popcorn in order to secure the highest possible popping expansion.

The experimental work reported in this publication was planned for the specific purpose of clarifying some of the present ideas regarding maturity in popcorn and to consider a few of the factors that affect the process of maturation.

MATURITY AS DETERMINED BY KERNEL MOISTURE

Brunson and Smith (5)* state that "complete normal maturity of the crop before the first killing frost is essential for best quality." They suggest that harvest should be deferred until the kernel moisture is reduced to 20 percent, and preferably 15 to 17 percent. Eldredge (8) and Eldredge and Thomas (6, 9) emphasize the importance of "complete maturity" in popcorn, but fail to define the term. Presumably they mean corn with a sufficiently low moisture content to be safe from freezing temperatures.

The experiments of Huelsen and Thompson (11), Huelsen and Bemis (13), and Bemis and Huelsen (4) indicated that maximum popping expansion was reached long before popcorn would be safe from frost.

Huelsen and Thompson (11) found that the popping expansion of white hulless popcorn was not impaired when harvested at kernel moistures between 16.2 and 23.1 percent and dried by means of forced hot air. Further experiments by Huelsen and Bemis (13) showed that Iopop 6 and Purdue 202 could be harvested up to 25-percent

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* This number and similar numbers in parentheses refer to "Literature Cited" on page 59.

kernel moisture and dried on the ear by forced air at 110° F. without materially affecting popping expansion. With the slower drying rate obtained when the ears are hung in mesh bags at room temperatures, the same hybrids could be harvested at kernel moisture up to 33 percent without impairing popping expansion. Additional experiments by Bemis and Huelsen (4) gave similar results.

DEVELOPMENT OF THE CORN KERNEL

Maize in the United States is usually classified into the five endosperm forms — dent, flint, pop, flour, and sweet. These were formerly considered either as separate species or as botanical varieties, but they are now believed to be genetic endosperm forms of *Zea mays* (Anderson and Cutler, 1). For the purposes of this publication, it is assumed that the morphological development of popcorn is similar to that of other starchy endosperm types of *Zea mays.*

Randolph (17) found no significant morphological differences in dent, flint, and sugary types of corn other than those that could be attributed to variations in size, shape, and degree of maturity of the kernels. Appropriate samples were taken at pollination and at 5-day intervals thereafter until 55 days had elapsed. At pollination the kernels measured 1.5 mm. in length, and 30 days later they measured 10.0 mm. At 35 days the length was 11.0 mm., and at 40 days, 11.5 mm. No further increases occurred. The length of the embryo increased rapidly up to 50 days following pollination, after which there was little change. Enlargement of the endosperm in the final stages consisted chiefly of increases in the size of the cells. Very little cell division occurred after 45 days. The kernel was assumed to be morphologically mature at this time, except for some further growth of the embryo, and the kernels were described as passing from the soft to the hard dough stage.

Kiesselbach (14) stated that the dent corn kernel is mature 50 days after fertilization; and in later work (15), stated that physiological maturity in dent corn is attained when the yield of grain (on a moisture-free basis) reaches equilibrium. Over a three-year period, ear moistures at this stage varied from 35 to 39 percent and averaged 37 percent. The corresponding kernel moistures varied from 33 to 35 percent and averaged 34 percent. In another experiment Kiesselbach concluded that corn was ripe 50 days after silking, at which time the ear moisture was 38 percent, the kernel moisture 34 percent, and the cob moisture 53 percent.

The above discussion indicates that there are several different ways to define maturity. First, there is the 18- to 15-percent kernel-moisture

stage, which is the proper maturity to harvest when the ears are to be stored in an outdoor corn crib. The second stage ranges up to 25-percent kernel moisture for ears to be dried by heated air. In the third stage the kernel moisture ranges from 35 to 30 percent. This range is equivalent to the kernel moisture 45 to 50 days after fertilization. Since corn is then morphologically mature, there is no discernible reason why it should fail to pop satisfactorily.

PURPOSE OF THE INVESTIGATIONS

The primary objective of the experiments reported here was to determine the relationship between maturity and popping expansion of popcorn, taking into consideration the different methods of handling and storing after harvest. The first requisite was to plan a series of successive harvests following the methods of Kiesselbach (15) and Miles and Remmenga (16). This was necessary because these investigators as well as others, Huelsen and Bemis (13) and Bemis and Huelsen (4), for example, have shown that the kernels and cobs dry at different rates.

Since weathering must be considered when popcorn is left in the field until late in the fall, this factor also received consideration. Experiments consisting of artificially freezing popcorn of several maturities were also included. With certain important variations, these experiments practically duplicated the results reported by Huelsen and Bemis (13).

MATERIALS AND METHODS

The experiments covered the three crop years 1954, 1955, and 1956. Since each season was an entity and the results could not be averaged, the experimental plans differed from year to year. The results of the 1955 experiments were transferred to I.B.M. punch cards and analyzed statistically. The 1954 and 1956 results required only limited statistical analysis.

All the data are based on two annual plantings at Urbana of the two hybrids, Iopop 6 and Purdue 202. Iopop 6 is a yellow Supergold three-way cross with relatively short ears, fairly thick cobs, and a tendency to produce two ears per stalk under favorable conditions. Purdue 202 is a yellow single cross of the South American type. The ear is long and slender with a small cob, and the kernels are much larger than those of Iopop 6. Purdue 202 produces only one ear per stalk. Eldredge and Thomas (9) state that the three-year average popping expansions of Iopop 6 and Purdue 202 were 37.9 volumes and 39.0 volumes respectively.

All the moisture samples in 1954 and 1956 were dried in duplicate in 307 × 306 open cans, 100 gm. of kernels being used in each can. In 1955 the ears were divided into three parts, and placed in 202 × 204 cans. A style V23 Despatch 220-volt electric drying oven was used. This oven had forced-air circulation and was operated at 80° C. with the vents wide open. All moisture samples were dried for 168 hours. In 1954 and 1956 the moistures were determined from the center sections of five ears. In 1955 five ears were also used in most of the experiments; but in a few experiments three ears were used, the upper and lower ears of Iopop 6 being kept separate. Each ear was tested individually by dividing it into three nearly equal parts — butt, center, and tip sections. The kernels were shelled by hand from each section and none were discarded. The moisture contents of all the cob sections were also obtained. In 1956, when the corn was too immature to shell, duplicate samples were taken from five ears and recorded as "ear moistures."

All samples were popped in late fall or early winter by reconstituting with water as described by Huelsen and Bemis (13). The so-called "Official Volume Tester" or "O.V.T." used by the trade was also used in these experiments to determine the popping expansion or volume of popcorn. Until 1956 the method of operation consisted in measuring a cup of raw popcorn, popping it, and then measuring the resulting expansion in a metal cylinder calibrated so that one inch of the cylinder was equivalent to the volume of the cup. The trade standard called for a minimum expansion of 30 volumes from one cup (volume) of raw popcorn. This method was open to objections because the amount of corn in the cup depended on the method of filling the cup. Huelsen and Thompson (11) pointed out that the weight deviations could be as high as 7 gm., which, in turn, would induce an error of 3 to 5 percent, depending upon the total weight of the corn in the cup.

In 1956 the trade adopted a different set of standards based on a weight-to-volume rather than a volume-to-volume relationship. The raw corn sample for testing consists of 150 gm. to be weighed out. A transparent plastic tube nominally 4.25 inches in diameter and calibrated in cubic inches of popped corn obtainable from one pound of raw corn is used for measuring the volume of popped corn. This system of calibration was devised so that the retailer (assuming that he knows the cubic contents of his bags) can calculate the number of bags of popped corn he can expect from one pound of raw corn. The factor used seems to be 3 — apparently on the assumption that 3 times 150 gm. equals 1 pound. Actually, 1 pound equals 453.6 gm., and 453.6 divided by 150 equals 3.024.

Since all the popping expansions through 1955 were recorded in volumes, it was necessary to interpret the 1956 results on the same basis. Correspondence with commercial producers indicated that the trade also wanted a conversion table. There are several methods of computing a conversion table, but the one used in this publication is based on the fact that in six years of experimental work all the popping samples were weighed after measuring. The method consisted in measuring a sample three to five times and weighing each time. The sample actually popped was then weighed, the weight being the average of the three to five trial measures. The weights ranged from 175 to 200 gm. per cup, and the average was 195 gm. for all types of popcorn. Thus, the ratio between the old and new systems is 0.7692 (150 divided by 195). One volume in the original metal tube nominally 4 inches in diameter is 12.57 cubic inches. Therefore, 12.57 times 0.7692 equals 9.669 cubic inches per volume in the new plastic tube. To convert to the calibrations in the new tube (cubic inches per pound of raw corn): 453.6 divided by 150 equals 3.024; and 9.669 times 3.024 equals 29.24, the factor for converting one volume of popped corn according to the old system to cubic inches per pound in the new system. The table below was computed by multiplying the number of volumes in the old system by 29.24.

Volumes in old tube	*Cu. in. per lb. in new tube*	*Volumes in old tube*	*Cu. in. per lb. in new tube*
24	702	33	965
25	731	34	994
26	760	35	1023
27	790	36	1053
28	819	37	1082
29	848	38	1111
30	877	39	1140
31	906	40	1170
32	936	41	1199

Many of the results are presented in graphic form taken either directly from the raw data, or indicated as being "calculated." The calculated curves are used where the trend is the more important factor, and are confined to showing the action of one character with respect to another. Thus the percent of moisture in the cobs was plotted in relation to the percent of moisture in the kernels. The actual percentages were paired and a smoothed curve estimated. The plus and minus deviations of the smoothed curve were balanced, and care was taken to keep the deviations as low as possible.

EXPERIMENTS IN 1954, 1955, AND 1956

Preliminary experiments were started in 1954 and briefly reported by Bemis and Huelsen (4). A summary of the results is given.

Cobs reached full maturity as determined by their constant dry weights before the moisture content of the kernels reached 50 percent, but they did not lose moisture until the kernel moistures were reduced to 30 percent. Although Iopop 6 and Purdue 202 matured at different rates, the relationship between cob and kernel moistures was the same. Owing to this constant relationship, the cob moisture of the two hybrids can be predicted once the kernel moisture is known. This information is valuable when popcorn is purchased on the ear directly from the field.

The kernels accumulated dry matter until the moisture tested 30 percent; then the cobs dried much more rapidly than the kernels. Increased dry weights of the kernels were closely related to increased popping expansion, the pooled correlation coefficient being 0.976. The maximum popping expansion was attained at kernel moistures between 35 and 30 percent, and neither increased nor decreased when harvest was delayed beyond this point.

The experiments in 1955 were conducted on an individual ear basis. Each ear was sectioned, and records of upper and lower ears of Iopop 6 were kept separately as previously described. The data were rounded off, transferred to punch cards, and processed through I.B.M. machines that printed the results. The 1956 experiments were conducted as described under "Materials and Methods." They were to a considerable extent a repetition of the 1954 tests and were added primarily because some of the 1954-1955 results varied so greatly from certain preconceived ideas.

Relation Between Kernel and Cob Moistures During Maturation

Maturation during the dry seasons of 1954 and 1956

Successive harvests in 1954 (Table 1) showed that both Iopop 6 and Purdue 202, which differ widely in plant and ear characters, resemble each other with respect to the relationship between kernel and cob moistures. At the earliest harvest, August 27, the kernels and cobs had about the same moisture content; but by September 15 the kernel moistures had decreased almost 20 percent while the cob moistures remained static. After September 15 the cobs also lost moisture rapidly.

Table 1. — Relation Between Percentages of Moisture in Kernels and Cobs of Iopop 6 and Purdue 202 Popcorn, Harvested Periodically, 1954

Harvest date	Iopop 6		Purdue 202		Rainfall (inches)
	Kernels	Cobs	Kernels	Cobs	
Aug. 27	49.6	53.8	48.3	49.0	0
30	42.5	52.3	43.5	47.0	.08
Sept. 1	41.2	50.8	41.6	46.3	0
3	41.4	48.0	41.2	47.4	0
6	36.1	49.3	37.6	46.7	0
8	34.9	48.7	33.9	47.5	0
10	33.5	49.3	32.1	48.1	0
13	30.9	48.2	31.4	49.0	0
15	29.8	48.6	30.6	48.6	0
17	27.0	46.9	28.1	44.9	0
20	23.1	40.4	26.5	45.2	.07
22	22.8	41.5	24.9	43.0	0
24	23.4	40.3	23.3	41.8	0
27	18.1	32.1	21.3	36.6	0
29	16.4	23.0	19.9	33.2	.09
Oct. 1	14.8	19.3	22.6	38.5	.09
4	14.0	16.7	19.8	33.7	.45
6	17.1	24.3	18.0	27.0	.11
8	13.8	16.3	17.5	25.3	0
11	14.3	17.6	17.1	24.8	2.21
13	15.2	20.2	17.5	27.2	.52
15	14.8	16.1	17.7	28.7	.67
18	14.0	15.6	16.6	22.4	.01
Total rainfall					4.30

Due to the dry weather in 1956, the harvested ears lost moisture very rapidly between September 17 and October 17 (Tables 2 and 3). The daily loss from the Iopop 6 kernels averaged 0.76 percent, and the Purdue 202 kernels, 0.74 percent. The cob moistures remained fairly static until the kernel moisture approached 30 percent.

By October 17 the kernel moisture had reached the low point of about 10 percent. Between October 17 and December 26, the harvests were placed on a weekly basis (Tables 2 and 3). Both the kernel and cob moistures increased gradually, reaching 17 to 18 percent by December 26. The remaining crop was harvested January 24, 1957, but there was no further increase in moisture content. These seasons may be considered unusual, since popcorn is more likely to lose moisture gradually until the content varies from 15 to 20 percent, depending upon the planting date. This would be consistent with the way dent corn matures as shown by Kiesselbach (15). However, unless the corn has an unduly high moisture content, it would be advisable to harvest as early as possible and place it in the crib. The effect of long field exposure on popping expansion will be discussed later in this study.

The 1956 harvest experiments were supplemented by controls consisting of four small instrument shelters mounted on posts three feet above ground and filled with popcorn at two different times (Tables 2 and 3). The four shelters were built to approximate U.S. Weather

Table 2. — Shelling Percentages and Percent Moisture in Kernels and Cobs of Iopop 6 When Harvested and When Removed From Corn Cribs, 1956

Date sampled	Percent moisture when harvested		Percent moisture when removed from crib				Shelling percentages when harvested			Rainfall	
			Sept. 24 harvest		Oct. 3 harvest						
	Kernels	Cobs	Kernels	Cobs	Kernels	Cobs	Entire ear wet basis	Kernel moisture adjusted[a]	Kernel and cob moistures adjusted[b]	Date	Inches
Sept. 14	35.3	51.9								Sept. 14	.15
17	32.9	48.7								15	.64
19	32.6	50.4					77.6	60.2	82.5		
21	33.2	50.8					79.1	60.7	83.7		
24	27.8	45.4	27.8[c]	45.4[c]			78.8	65.3	83.1	23	.02
26	26.2	46.9	....	....			78.6	66.7	83.6		
28	23.8	47.5	....	....			79.9	70.0	83.9		
Oct. 1	20.3	31.8	....	....			81.7	74.8	83.9		
3	17.7	28.9	16.8	22.1	17.7[c]	28.9[c]	80.3	75.9	82.5		
5	16.8	23.7	....	....	....	....	83.2	79.6	84.4		
8	20.2	29.2	....	....	....	....	82.2	75.4	83.9		
10	17.1	26.1	11.1	10.2	13.2	12.8	82.7	78.8	84.3		
12	14.0	17.2	....	....	....	....	82.8	81.9	83.3		
15	12.1	13.2	....	....	....	....	84.1	85.0	84.2		
17	10.1	9.7	10.6	9.9	10.3	9.4	84.2	87.0	84.1		
24	11.4	11.8	10.8	10.5	11.0	10.8	83.9	85.4	83.9		
31	12.1	12.3	12.0	12.1	12.2	12.0	83.8	84.7	83.8	Oct. 25-26	.39
Nov. 7	12.6	12.5	12.9	12.9	12.5	12.6	83.6	84.0	83.6	Nov. 6	.38
14	12.2	11.2	11.9	10.4	11.6	11.0	84.1	84.8	83.9	15	.57
21	13.1	14.9	13.3	13.0	13.4	13.8	83.9	83.8	83.9	20	.99
28	12.8	12.4	13.3	12.8	13.4	13.1	84.3	84.5	84.2	23-28	.17
Dec. 5	13.0	13.4	13.3	13.7	13.6	13.4	84.1	84.1	84.2		
12	14.5	15.5	14.9	14.0	14.4	14.2	83.3	81.9	83.5	Dec. 6-11	1.71
19	15.9	17.0	16.1	16.0	15.8	16.1	83.0	80.3	83.2	14-19	.36
26	16.9	18.7	17.2	16.9	17.3	17.4	84.1	80.3	84.4	21-26	.17

[a] Kernel moisture adjusted to 13 percent.
[b] Kernel and cob moistures adjusted to 13 percent.
[c] Moisture content at the time cribs were filled.

Table 3. — Shelling Percentages and Percent Moisture in Kernels and Cobs of Purdue 202 When Harvested and When Removed From Corn Cribs, 1956

Date sampled	Percent moisture when harvested		Percent moisture when removed from crib				Shelling percentages when harvested			Rainfall	
			Sept. 24 harvest		Oct. 3 harvest						
	Kernels	Cobs	Kernels	Cobs	Kernels	Cobs	Entire ear wet basis	Kernel moisture adjusted[a]	Kernel and cob moistures adjusted[b]	Date	Inches
Sept. 14	36.1	47.7								Sept. 14	.15
17	32.6	46.7								15	.64
19	31.5	46.8					76.6	61.2	82.9		
21	29.4	43.5					77.6	63.0	81.2	23	.02
24	28.3	42.9	28.3[c]	42.9[c]			75.9	62.6	79.8		
26	21.5	33.1	....	....			78.0	70.4	80.6		
28	24.1	39.7	....	....			77.9	68.0	81.6		
Oct. 1	17.5	25.2	....	....			79.1	75.0	80.7		
3	16.8	22.3	14.8	19.8	16.8[c]	22.3[c]	81.2	77.6	82.3		
5	18.0	23.5	....	....	....	....	81.2	76.5	81.2		
8	13.7	15.8	....	....	....	....	80.8	80.1	81.2		
10	13.0	13.4	11.9	10.4	12.4	13.8	81.0	81.0	81.1		
12	15.4	19.6	....	....	....	....	80.9	78.7	81.7		
15	14.0	15.8	....	....	....	....	81.3	80.4	81.6		
17	10.2	9.7	10.4	9.5	10.6	9.8	81.3	83.9	81.2		
24	11.1	11.1	11.0	11.4	10.9	10.5	80.8	82.5	80.8		
31	11.8	12.8	12.6	11.7	12.0	12.4	81.7	82.9	81.9	Oct. 25-26	.39
Nov. 7	12.5	13.1	12.8	12.9	13.1	13.1	80.3	80.8	80.4	Nov. 6	.38
14	11.9	11.8	11.8	11.1	11.8	10.9	80.9	81.9	80.8	15	.57
21	12.6	13.9	13.5	13.3	13.4	14.4	80.7	81.0	80.9	20	.99
28	12.6	13.0	13.5	13.4	13.3	13.4	80.0	80.4	80.1	23-28	.17
Dec. 5	13.1	13.4	13.6	13.8	13.8	13.6	80.5	80.4	80.5		
12	14.8	15.3	14.7	14.4	14.4	14.6	81.6	79.9	81.7	Dec. 6-11	1.71
19	15.2	16.6	16.0	16.2	15.8	16.0	80.4	78.4	80.4	14-19	.36
26	16.5	18.7	17.8	17.4	17.2	17.6	80.7	77.5	81.1	21-26	.17

[a] Kernel moisture adjusted to 13 percent.
[b] Kernel and cob moistures adjusted to 13 percent.
[c] Moisture content at the time cribs were filled.

Bureau standards, and when completely filled with corn, had a capacity of 4 bushel baskets of Iopop 6 and 4.5 baskets of Purdue 202. Two cribs were filled with each hybrid September 24, and two more were filled October 3.

Because of dry weather, the moisture losses from the popcorn in the field and that in the cribs were practically the same until October 17. After October 17 the cribbed popcorn picked up moisture at practically the same rate as that left on the stalk in the field. Judging from these results, it is doubtful whether popcorn should be stored for long periods in outdoor cribs.

Maturation in relation to the weather

The rainfall during the actual harvests of 1954 and 1956 is shown in Tables 1 and 2 respectively. A three-year summary appears in Table 4. The 1956 season was the driest of the three under consideration, with September temperatures nearly normal and October temperatures much above normal. The 1954 season was characterized by one of the driest Septembers on record and above-normal rainfall in October. The temperatures were much above normal. The 1955 season was warm, with an extremely wet October. As might be expected, the drying rates per day were most rapid in 1956 and slowest in 1955.

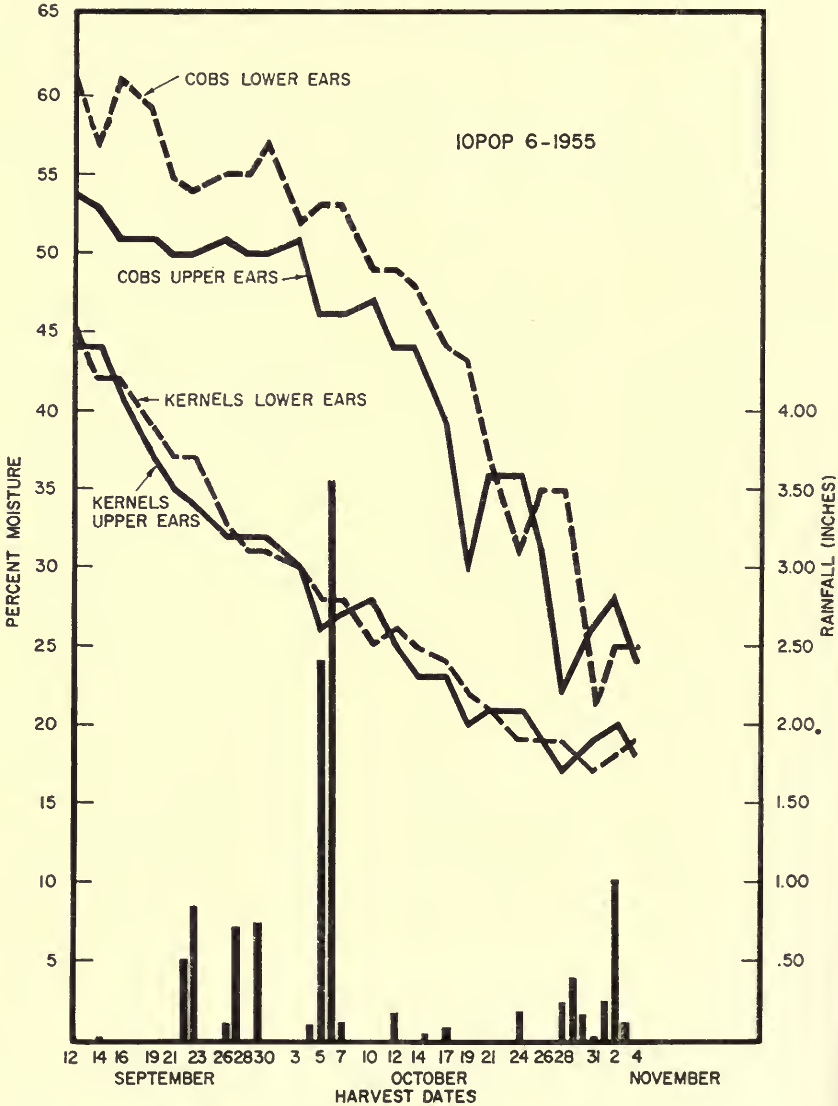
The belief commonly exists that heavy rains cause an increase in moisture content in the kernels and cobs of popcorn. While the plant is still actively developing and the vascular system functioning, this is probably true; but during all three harvest years the plants were definitely dying when harvest started. There is slight evidence in 1954 (Table 1) that the heavy rainfall of October 11 and 13 caused a nominal increase in kernel and cob moisture. In contrast, the extremely heavy rains October 5 and 6, 1955, totaling 5.97 inches, failed to have the slightest effect on kernel and cob moistures (Fig. 1).

The moisture loss per day from kernels and cobs was most rapid in 1956 and slowest in 1955 (Table 4). However, consideration must be given to the initial and final moisture contents. In 1955 the initial moistures in the kernels of upper and lower ears of Iopop 6 were 44 and 45 percent respectively (Fig. 1) and 45 percent for Purdue 202. The final moisture contents in the same order were 18, 19, and 16 percent. The total kernel moistures lost in 1955 were 26 and 26 percent for Iopop 6 (Fig. 1), and 29 percent for Purdue 202.

In 1956 the initial and final moisture contents in the kernels of both hybrids were much lower. Iopop 6 and Purdue 202 lost kernel moistures totaling 25.2 and 25.9 percent respectively between September 14 and October 17, 1956 (Tables 2 and 3). Thus in 1955, 53 days were re-

Table 4. — Drying Rates of Kernels and Cobs of Iopop 6 and Purdue 202 in Relation to the Weather

Month and year	Temperatures (degrees)		Rainfall (inches)			Harvest period		Percent moisture loss per day from					
								Iopop 6				Purdue 202	
								Upper ears		Lower ears			
	Mean	Departure from mean	Total	Departure from normal	During harvest period	Dates	Number of days	Kernels	Cobs	Kernels	Cobs	Kernels	Cobs
Sept. 1954	71.6	+5.5	.25	−3.01	4.30	Aug. 27 to							
Oct. 1954	56.8	+2.7	4.46	+1.93		Oct. 18	52	.68	.73			.60	.51
Nov. 1954	43.4	+2.5	.53	−2.10									
Sept. 1955	69.7	+3.6	3.15	− .11	11.92	Sept. 12 to							
Oct. 1955	56.3	+2.2	7.42	+4.89		Nov. 4	53	.49	.57	.49	.68	.55	.57
Nov. 1955	37.9	−3.5	2.51	+ .08									
Sept. 1956	65.5	−1.2	1.25	−2.01	0.81	Sept. 14 to							
Oct. 1956	61.7	+6.4	.39	−2.37		Oct. 12	28	.76	1.24			.74	1.04
Nov. 1956	40.3	−1.1	2.11	− .32									
Dec. 1956	35.5	+5.8	2.65	+ .51									



Percent moisture in kernels and cobs of upper and lower ears of Iopop 6 at successive harvest dates with rainfall records interpolated (averages of 5 ears, 1955). (Fig. 1)

quired for the popcorn to lose about the same percentage of moisture that was lost in 28 days in 1956 (Table 4).

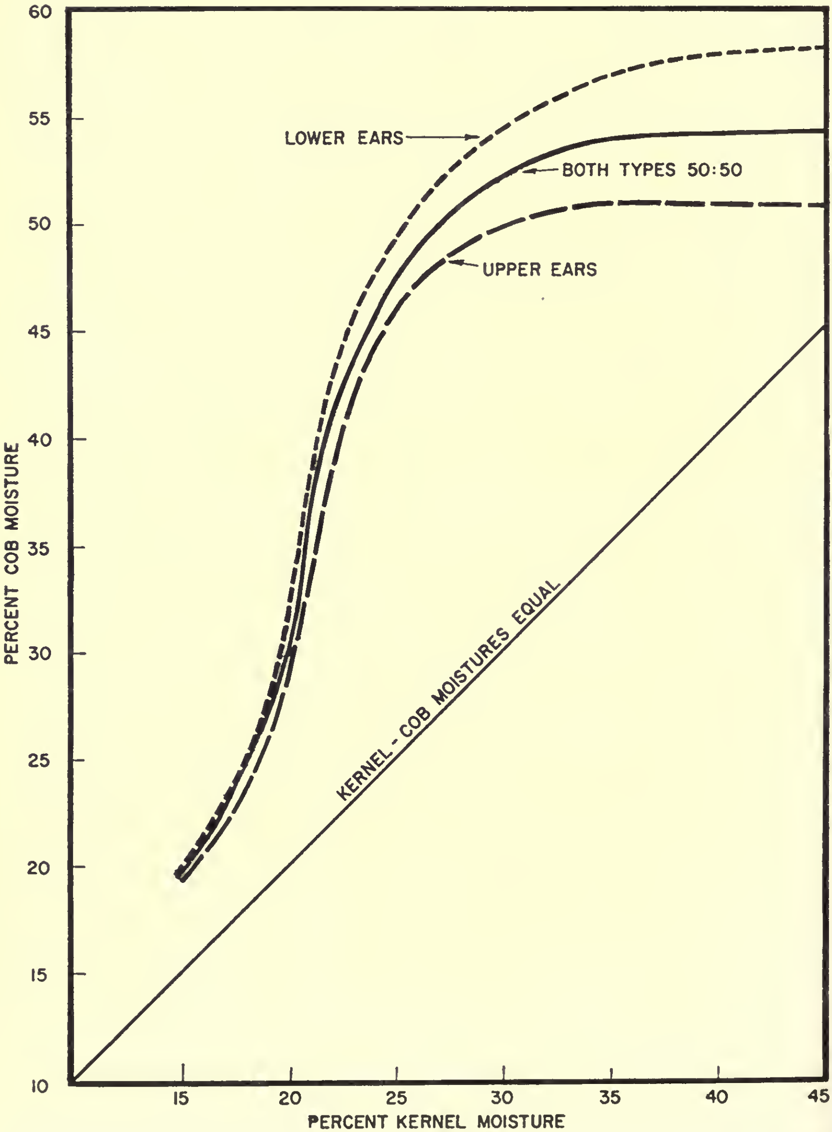
The mean temperatures in Table 4 fail to account for these differences. In 1955, both September and October temperatures were above normal; but in 1956, September was below normal and October much above normal. The differences in drying rate must have been due to the heavy rainfall in 1955 as contrasted with the lack of rainfall in 1956. The curves in Fig. 1 do not show any increase in moisture in the kernels or cobs following a rain, but rain rather than low temperature lengthens the drying period.

In 1956 popcorn was harvested to December 26, and the moisture content of both cobs and kernels increased gradually after October 17 (Tables 2 and 3) because of high humidity and above normal rainfall (Table 4). Fifteen foggy days between November 1 and December 22 would account for the increases in moisture content of the corn both outdoors and in cribs.

Maturation of upper and lower ears compared

The observations with respect to upper and lower ears were confined to Iopop 6, which, under favorable conditions, develops a second ear. The harvest moistures for Iopop 6 in 1955 (Fig. 1) show that the kernels of both upper and lower ears had about the same moisture content at the 45-percent stage; but as maturity advanced, the kernels from the upper ears lost moisture slightly faster until within the 30 to 35 percent range. Beyond this point the kernels matured at about the same rate. With a few exceptions, the cobs of the upper ears had less moisture than the cobs of the lower ears. The exceptions were probably due to errors in sampling.

Because the 1955 kernel moistures were recorded by single ears, each ear could be classified according to its respective cob moisture. The number of ears falling into each class varied from 1 to 15. New curves were then calculated, those for Iopop 6 appearing in Fig. 2. These curves closely resemble the results obtained in 1954 by Bemis and Huelsen (4), who found that the cobs lost practically no moisture until the kernel moisture had decreased to 30 percent. Their data were based only on Purdue 202 and upper ears of Iopop 6. The curve for upper ears of Iopop 6 in Fig. 2 tends to follow this pattern; but the cobs of lower ears, which contain considerably more moisture, start to dry out rapidly when the kernel moisture reaches 35 percent. When both upper and lower ears were combined on a 50:50 basis, which would assume that all plants bore two ears (Fig. 2), the sharp drop in cob moisture occurred between 30 and 35 percent kernel moisture.



Calculated curves showing relationship between upper and lower ears of Iopop 6 at harvest (averages of 5 ears, 1955). (Fig. 2)

In Fig. 3 the 1952, 1953, and 1954 kernel-cob relationships based only on upper ears have been combined into a single curve and compared with the results obtained in 1955. The two curves for upper ears are so much alike that it may be assumed that the cobs of Iopop 6 lose no moisture until the kernel moisture falls below 35 percent. The curve representing both upper and lower ears in a 50:50 ratio shows substantially the same trend. The lower ears alone also show a similar trend (Fig. 2). The kernel-cob moisture relationships of Purdue 202 in 1955 were also plotted on a single-ear basis, and the results were practically identical with those of Iopop 6.

Practical application of kernel-cob moisture relationships

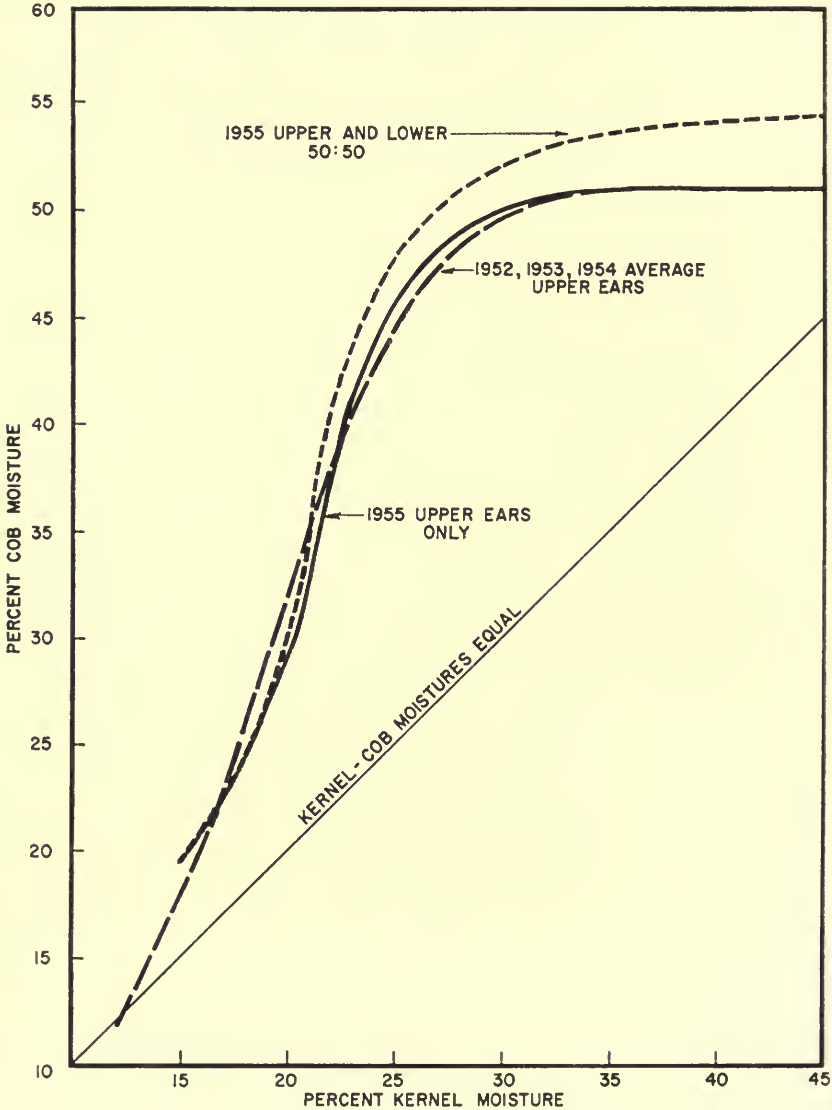
The moisture differences between upper and lower ears and between kernels and cobs have a practical bearing at harvest. Unless the ears are artificially dried, very little popcorn is harvested at kernel moistures higher than 20 percent. At harvest the kernels of lower ears contain slightly more moisture than the kernels of upper ears, and the cobs of both upper and lower ears contain considerably more moisture than the kernels. The following summary shows the relationship.

	Cob moisture at 20-percent kernel moisture (percent)
1952, '53, '54 Iopop 6, upper ears	31.5
1953, '54 Purdue 202	33.0
1955 Iopop 6, upper ears	28.5
1955 Iopop 6, lower ears	31.5
1955 Purdue 202	31.5
1956 Iopop 6, upper ears	35.0
1956 Purdue 202	29.0

Although variable from year to year, Iopop 6 cobs contain 8.5 to 15 percent more moisture than the kernels at 20-percent kernel moisture. In Purdue 202 the range is from 9 to 13 percent. Thus, if popcorn containing 20-percent kernel moisture is placed in a crib, the kernels will absorb moisture from the cobs as shown by Huelsen and Thompson (11), and damage may result if weather conditions are unfavorable for drying.

Relation between butt, center, and tip sections of ear

At harvest. Huelsen and Thompson (11) and Huelsen and Bemis (13) found that artificial drying of popcorn on the ear was responsible for varying losses in popping expansion. When popcorn was

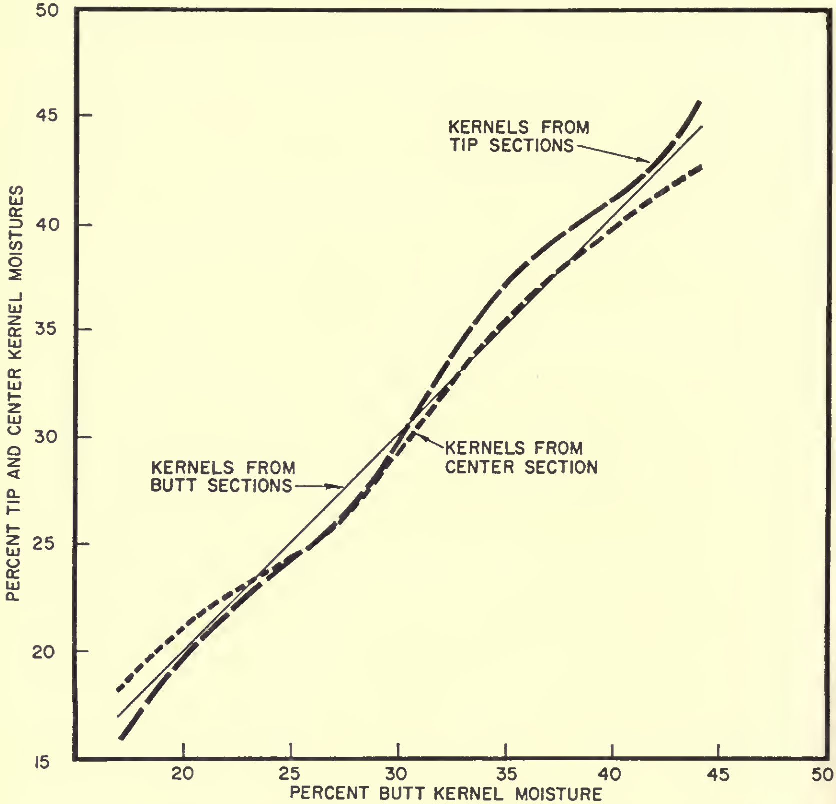


Calculated curves showing relationship between kernel and cob moistures in Iopop 6 at harvest. The combined averages of 5 upper ears for 1952, 1953, and 1954 are compared with the average of 5 ears in 1955. (Fig. 3)

dried in open mesh bags at room temperatures, popping was not adversely affected unless the kernel moisture exceeded 33 percent. Below 25-percent kernel moisture, the popping expansion of artificially dried popcorn was only slightly affected; but as the moistures increased above 25 percent, the losses in popping expansion became more severe. Outdoor controls popped better than either room-dried corn or corn dried at 110° F. This fact led to the conclusion that speed of drying had something to do with the adverse effects, especially since the controls had the slowest rate of drying, and the rate was most rapid at 110° F. Shelled corn dried more rapidly than ear corn at equivalent temperatures, and popping quality was even more adversely affected.

No reason could be assigned for these decreases in popping expansion, since both commercial dent and sweet corn seed are dried at 110° F. without injury to the germination. The theory was advanced that the various sections of the ear did not lose moisture at the same rate. Under slow drying conditions no damage would result, but rapid drying at 110° F. might impair popping expansion. Thus the kernels of an ear might average 25-percent moisture, but one ear section could be higher and another lower than this amount. All the damage might then be confined to one section of the ear. In 1955 the ears were divided into three sections, butt, center, and tip, in order to test this hypothesis. The ears were sectioned and shelled within two hours of harvest, thus eliminating the factor of absorption of moisture from the cobs by the kernels.

A typical set of curves showing the kernel moisture relationships by ear section at harvest appears in Fig. 4 and the equivalent cob moistures in Fig. 5. The method used in calculating these curves was to assume that the regressions for the butt sections would be a straight line. If the tip and center sections dried at a uniform rate in relation to the butt sections, their respective regressions would also consist of straight lines. The data for the kernels of the upper ears of Iopop 6 in Fig. 4 indicate that the tip and center sections deviated somewhat from a straight-line regression. Above 30-percent butt kernel moisture, the tip sections contained slightly more moisture than the butt and center sections. Below 22-percent butt kernel moisture, the center sections tended to maintain a slightly higher moisture level than either the butt or tip sections. The lower ears of Iopop 6 showed the same trends. In contrast, the tip sections of Purdue 202 contained slightly less moisture than the butt and center sections at all stages. For all



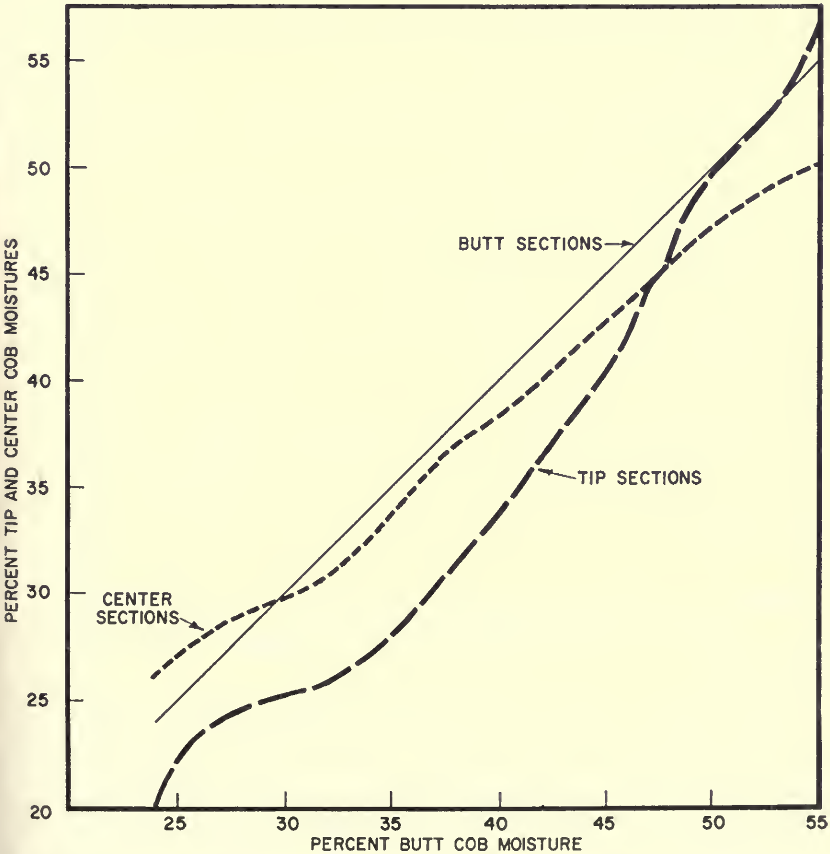
Calculated curves showing percent moisture at harvest in Iopop 6 kernels from butt, center, and tip sections of upper ears. The center and tip sections are plotted in relation to the butt section (averages of 5 ears, 1955). (Fig. 4)

practical purposes, however, it may be assumed that the kernels of both hybrids dried at the same rate in all three parts of the ear.

The cob moistures of Iopop 6 upper ear sections (Fig. 5) differed widely enough to have some practical significance. The tip sections contained considerably less moisture than the butt and center sections at all stages below 50- to 47-percent butt moisture. Above 30-percent butt moisture, the center sections maintained a consistently lower moisture content than the butts. The lower ears of Iopop 6 showed somewhat similar trends. Below 54-percent butt moisture, the tip sections contained considerably less moisture than the butts. The center sections contained less moisture than the butt sections above 40-per butt moisture. Below this point the moistures were practically same.

The tip sections of Iopop 6 and Purdue 202 showed similar trends, except that the Purdue 202 tip sections contained less moisture than the butt sections at all stages. Below 44-percent butt moisture, the tip sections of Purdue 202 contained less moisture than the center sections. Below 37-percent butt moisture, the butt and center sections contained about the same amount of moisture.

In general, the differences in kernel moisture of the butt, center, and tip sections of both hybrids were too small to be worth considering; but it is worth noting that the cob moistures of the tip and center sections of Iopop 6 were lower than the butts. In Purdue 202 only the tip sections tended to maintain a consistently lower moisture than the butt sections.



Ca ulated curves showing percent moisture at harvest in Iopop 6 cobs fr butt, center, and tip sections of upper ears. The center and tip sec- t s are plotted in relation to the butt section (averages of 5 ears, 1955). (Fig. 5)

During drying at room temperatures. It may be assumed from these differences in initial cob moistures that the drying rates of the butt, center, and tip sections of the ears might differ under the environmental conditions of an unheated attic room. The entire ears were placed in mesh bags and were sampled and sectioned as shown in Table 5. The total moisture losses were divided by the number of drying days to give the daily moisture loss. The kernels and cobs of the butt and tip sections lost moisture at a more rapid daily rate than the center sections of both Iopop 6 and Purdue 202. And with one exception, the center sections of the kernels and cobs contained more moisture at the end of the drying period than the butt and tip sections. The kernels from the butt sections of Iopop 6 maintained a slightly lower moisture content than the tip and center sections during most of the drying period. In Purdue 202 the relationship between the ear sections varied, but the differences were small.

All the data in Table 5 were calculated as curves, but only the cob moistures of Iopop 6 upper ears are shown in Fig. 6. The butt and tip sections of the cobs maintained practically the same moisture content during the entire drying period. The moistures in the center sections were more variable. Above 40-percent cob moisture in Iopop 6 (Fig. 6), and above 36 percent in Purdue 202, the center sections contained less moisture than the butt sections. Below 35-percent moisture, the center sections of the cobs of both hybrids contained more moisture than either butts or tips. Since the daily moisture losses of the center sections of the cobs were consistently lower than those of the butt and tip sections (Table 5), it is possible that some of the moisture in the centers of the cobs was transported to the two ends during the drying process. This possibility seemed to be confirmed by the final moistures in Table 5, where the center sections contained more moisture than the butt and tip sections.

Relation Between Kernel Moistures, Cob Moistures, and Shelling Percentages

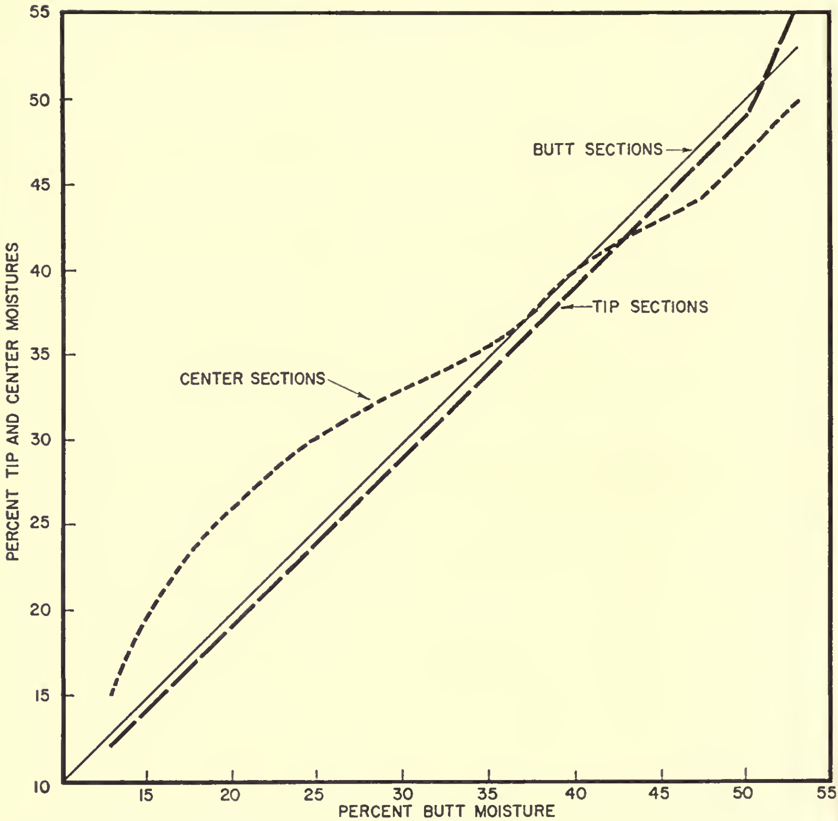
At harvest

Date of harvest had a considerable effect on shelling percentages. In 1955 Iopop 6 and Purdue 202 were harvested at three different moisture levels. Each harvest was stored in mesh sacks hung in an unheated attic. The corn was sampled on Monday, Wednesday, and Friday of each week. The kernel and cob moistures, together with the shelling percentages, were recorded. The data were calculated as curves (Figs. 7 and 8). All three harvests dried at about the same rate,

Table 5. — Percent Moisture at Harvest in Butt, Center, and Tip Sections of Kernels and Cobs of Iopop 6 and Purdue 202 Dried at Room Temperature, 1955

(Averages of 3 ear samples)

Date sampled	Iopop 6						Purdue 202					
	Kernels			Cobs			Kernels			Cobs		
	Butts	Centers	Tips	Butts	Centers	Tips	Butts	Centers	Tips	Butts	Centers	Tips
Harvested on September 12												
Sept. 12	43	43	45	54	51	57	46	44	44	51	46	48
14	35	37	41	53	51	55	40	38	39	50	45	47
16	30	29	31	49	45	48	35	35	35	51	47	48
19	20	21	24	30	32	31	25	25	24	40	38	37
21	16	18	18	23	25	21	23	24	23	36	36	35
23	21	23	21	36	37	28	16	21	20	19	28	29
26	14	16	15	13	21	17	16	18	16	23	24	21
28	13	13	13	13	10	11	11	13	14	12	13	13
30	14	17	14	15	22	13	13	13	12	11	13	12
Total moisture loss	29	26	31	39	29	44	33	31	32	40	33	36
Loss per day	1.61	1.44	1.72	2.17	1.61	2.44	1.83	1.72	1.78	2.22	1.83	2.00
Harvested on September 30												
Sept. 30	32	31	32	53	48	50	30	29	29	48	47	47
Oct. 3	26	27	28	47	46	47	27	28	27	46	44	46
5	21	22	21	36	36	33	23	25	23	37	39	37
7	23	24	20	39	39	37	22	23	21	38	38	34
10	19	20	17	30	31	26	20	22	21	34	31	33
12	19	22	20	28	34	31	18	19	16	26	28	20
14	21	25	22	37	43	35	16	18	16	19	26	21
17	14	19	16	16	30	24	16	17	16	22	24	20
19	15	19	28	19	29	23	16	17	15	20	24	17
21	14	16	15	18	19	14	13	16	14	13	17	12
24	14	17	15	14	20	13	14	17	15	17	22	17
Total moisture loss	18	14	17	39	28	37	16	12	14	31	25	30
Loss per day	0.72	0.56	0.68	1.56	1.12	1.48	0.64	0.48	0.56	1.24	1.00	1.20

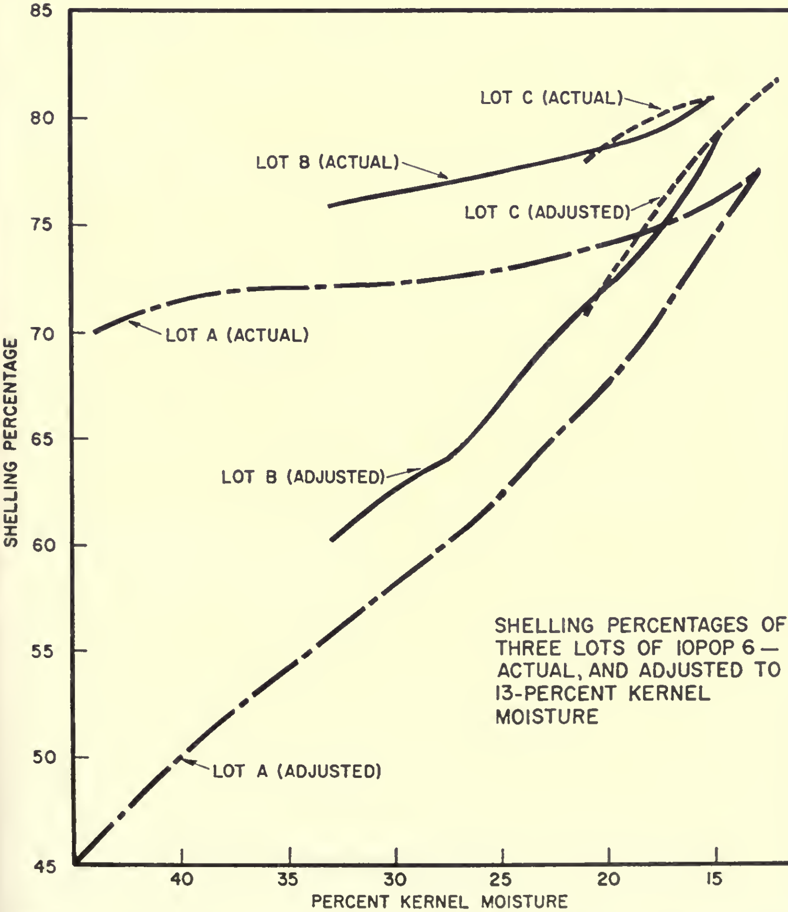


Calculated curves showing percent moisture in Iopop 6 cobs from butt, center, and tip sections of upper ears. The center and tip sections are plotted in relation to the butt section. The sections were sampled three times weekly while drying at room temperatures (averages of 3 ears, 1955). (Fig. 6)

but the shelling percentages of the first series, harvested at 44- to 45-percent kernel moisture, were consistently the lowest. The second series, harvested at 30- to 33-percent kernel moisture, had shelling percentages as high as those from the final series, harvested at 19- to 21-percent kernel moisture. Thus, from the standpoint of shelling percentage, nothing is gained by delaying harvest after the kernels reach 30-percent kernel moisture.

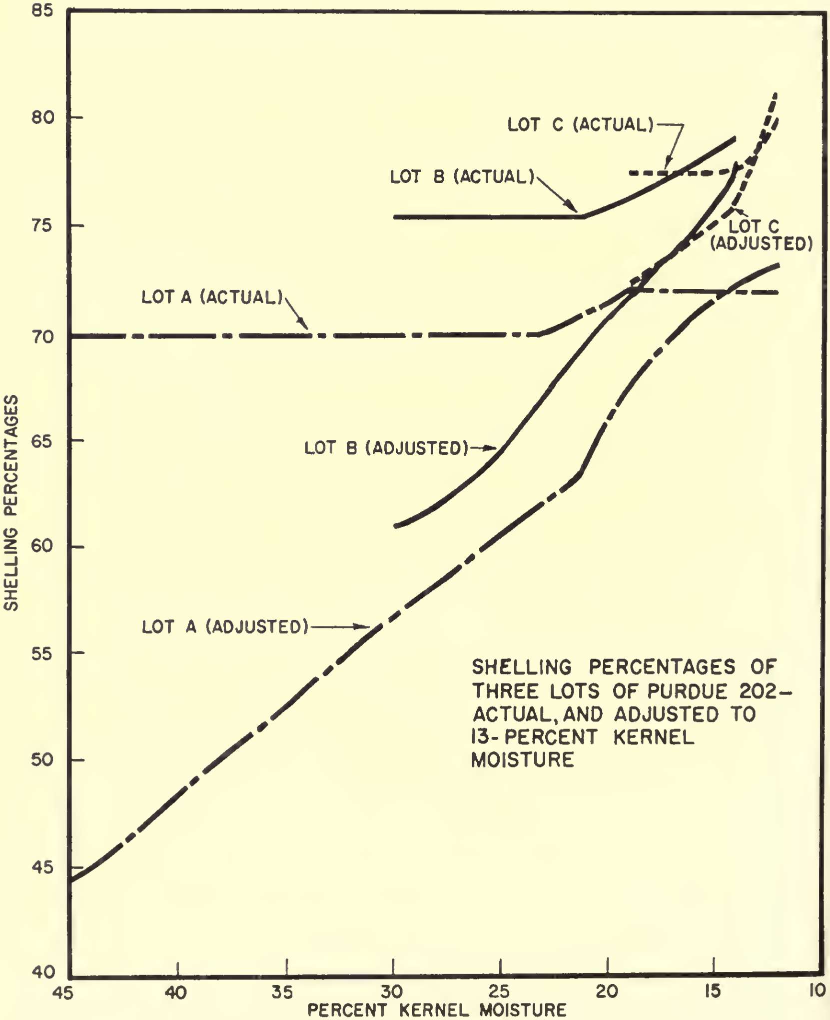
Miles and Remmenga (16) discuss in detail the relationships of kernel to cob moistures in dent corn and the effect of their variation on shelling percentages. Following their lead, an attempt was made to utilize the kernel-cob moisture relationships which have just been discussed.

Kernel and cob moistures in Iopop 6 were recorded for the five crop years 1952-1956, and in Purdue 202 for the four crop years 1953-1956. Using three years' data (1952-1954) on Iopop 6 and two years' data (1953-1954) on Purdue 202, Bemis and Huelsen (3) computed a table showing the kernel-cob moisture relationships of these hybrids and estimated the shelling percentages within the kernel moisture range of 13 to 33 percent. They assumed that by the time the kernel moisture reached 33 percent both kernels and cobs would be fully mature, and the shelling percentages computed on a dry-weight basis would not change. From the data available they found that the



Shelling percentages of Iopop 6 harvested at three successive maturities and sampled three times weekly while drying at room temperatures, 1955. (Fig. 7)

dry-weight shelling percentage was 83.7 percent for Iopop 6 and 80.5 percent for Purdue 202. These shelling percentages were checked again in 1956. From the first 23 successive harvests of Iopop 6, beginning September 19 in Table 2, the average dry-weight shelling percentage checked exactly at 83.7 percent. A similar check on Purdue 202, starting with the harvest of September 19 in Table 3, showed that the 23



Shelling percentages of Purdue 202 harvested at three successive maturities and sampled three times weekly while drying at room temperatures, 1955. (Fig. 8)

harvests averaged 81.1 dry-weight shelling percent, only slightly higher than the 80.5 percent used by Bemis and Huelsen (3). The formula used by Bemis and Huelsen follows:

$$\text{Shelling percentage} = 100\,A\left[\frac{100 - C}{100 \times (100 - K) - A \times (C - K)}\right]$$

A is the average dry-weight shelling percentage — 83.7 for Iopop 6 and 80.5 for Purdue 202.
C is the cob moisture.
K is the kernel moisture.

The values calculated by Bemis and Huelsen are reproduced in Table 6 under the headings "Calculated." To use the above formula, assume that a given lot of Iopop 6 contains 25-percent kernel moisture. From Table 6 the cob moisture is 44.3 percent. Substituting, the formula now becomes:

Shelling percentage =

$$100 \times 83.7\left[\frac{100 - 44.3}{100 \times (100 - 25.0) - 83.7 \times (44.3 - 25.0)}\right] = 79.3$$

The calculated shelling percentage at harvest shown in Table 6 is 79.1 percent. The slight discrepancy of 0.2 percent is due to the fact that the calculations from the formula were plotted on a curve that had been smoothed. The calculated values in Table 6 were taken from the curve.

The calculated shelling percentages were checked against actual shelling percentages from the 1955 and 1956 crops. The two percentages were close enough to justify using the calculated values to predict the probable shelling percentages of Iopop 6 and Purdue 202. It is not difficult to compute shelling percentage tables for any hybrid if the kernel and cob moistures are obtained from six to ten harvests at various moistures between 33 and 13 percent. Smoothed curves may be drawn and the shelling percentages calculated from the formula shown above.

The shelling percentages in Table 6 will prove useful in finding the shelling percentage at 13-percent kernel moisture for corn with kernel moistures up to 33 percent. For example, a lot of Iopop 6 that tests 22-percent kernel moisture in the field has a calculated cob moisture of 39.9 percent and a shelling percentage of 79.7, or 71.5 at 13-percent kernel moisture. The conversion to 13-percent kernel moisture is as follows:

A 100-pound lot of Iopop 6 containing 22-percent kernel moisture will shell out 79.7 pounds of kernels. These kernels will contain 17.53 pounds of water (79.7 times 22 percent). The number of pounds of moisture-free kernels in 100 pounds of ear corn at harvest equals 79.7

Table 6. — Relation Between Kernel and Cob Moistures and Shelling Percentages of Iopop 6 and Purdue 202 on a Calculated and Actual Basis at Harvest and Adjusted to 13-Percent Kernel Moisture

Percent kernel moisture	Iopop 6						Purdue 202					
	Calculated			Actual (average 1955-56)			Calculated			Actual (average 1955-56)		
	Percent cob moisture	Shelling percentage: At harvest	Shelling percentage: At 13-percent kernel moisture	Percent cob moisture	Shelling percentage: At harvest	Shelling percentage: At 13-percent kernel moisture	Percent cob moisture	Shelling percentage: At harvest	Shelling percentage: At 13-percent kernel moisture	Percent cob moisture	Shelling percentage: At harvest	Shelling percentage: At 13-percent kernel moisture
33	51.4	78.7	60.6	51.8	77.8	60.0	49.6	75.7	58.3	47.0	74.8[a]	57.8[a]
32	50.8	78.7	61.5	51.1	78.0	61.0	49.2	75.5	59.0	46.8	76.0	60.2
31	50.3	78.7	62.3	50.4	78.2	62.0	48.7	75.4	59.8	46.4	76.0	60.8
30	49.4	78.7	63.2	49.8	78.3	63.0	48.0	75.4	60.7	45.8	76.0	61.6
29	48.5	78.7	64.2	49.4	78.4	64.0	47.3	75.4	61.5	45.0	76.1	62.3
28	47.6	78.8	65.2	49.0	78.6	64.9	46.5	75.4	62.3	44.2	76.2	63.0
27	46.6	78.9	66.2	48.4	78.7	66.0	45.4	75.5	63.4	43.4	76.3	63.8
26	45.5	79.0	67.2	48.0	78.8	67.0	44.3	75.6	64.3	42.4	76.4	64.9
25	44.3	79.1	68.2	47.0	79.0	68.0	43.0	75.8	65.3	41.2	76.6	65.9
24	43.0	79.3	69.3	45.6	79.4	69.2	41.5	76.1	66.5	39.6	76.9	67.0
23	41.5	79.5	70.4	43.6	80.0	70.4	40.0	76.3	67.5	37.8	77.2	68.0
22	39.9	79.7	71.5	40.5	80.6	71.7	38.1	76.6	68.7	35.4	77.3	69.0
21	37.6	80.1	72.7	36.4	81.0	73.0	35.5	77.0	69.9	32.8	77.6	70.2
20	34.7	80.6	74.1	32.4	81.4	74.4	33.0	77.5	71.3	30.2	78.2	71.6
19	31.6	81.2	75.6	29.4	81.8	75.5	30.2	78.1	72.9	27.2	78.6	73.2
18	28.5	81.7	77.0	26.7	82.1	76.7	27.0	78.6	74.1	24.2	79.0	74.7
17	25.0	82.2	78.4	24.2	82.6	78.0	23.5	79.2	75.6	21.5	79.5	76.2
16	21.7	82.6	79.8	22.0	83.0[a]	79.0[a]	19.0	79.9	77.2	19.5	80.0	77.2
15	18.6	83.0	81.1	19.8	83.0[a]	80.0[a]	16.5	80.2	78.4	17.8	81.0[a]	80.0[a]
14	15.7	83.3	82.3	17.0[a]	83.3[a]	81.0[a]	14.3	80.5	79.6	15.6	81.0[a]	80.5[a]
13	13.0	83.6	83.6	15.0[a]	83.9[a]	83.0[a]	12.7	80.6	80.6	14.0[a]	81.0[a]	81.0[a]
12	11.0	83.7		13.0[a]	84.0[a]							
Number of samples	73			51	51	51	60			51	51	51

[a] One year only.

minus 17.53 or 62.17 pounds. To convert to kernels at 13-percent moisture, divide 62.17 by 100 minus 13 (62.17 divided by 87), which equals 0.715. To find the number of pounds of kernels containing 13-percent moisture, multiply 0.715 by 100, which equals 71.5 pounds. Table 6 shows that the shelling percentage of Iopop 6 harvested at 22-percent kernel moisture and adjusted to 13-percent kernel moisture is 71.5.

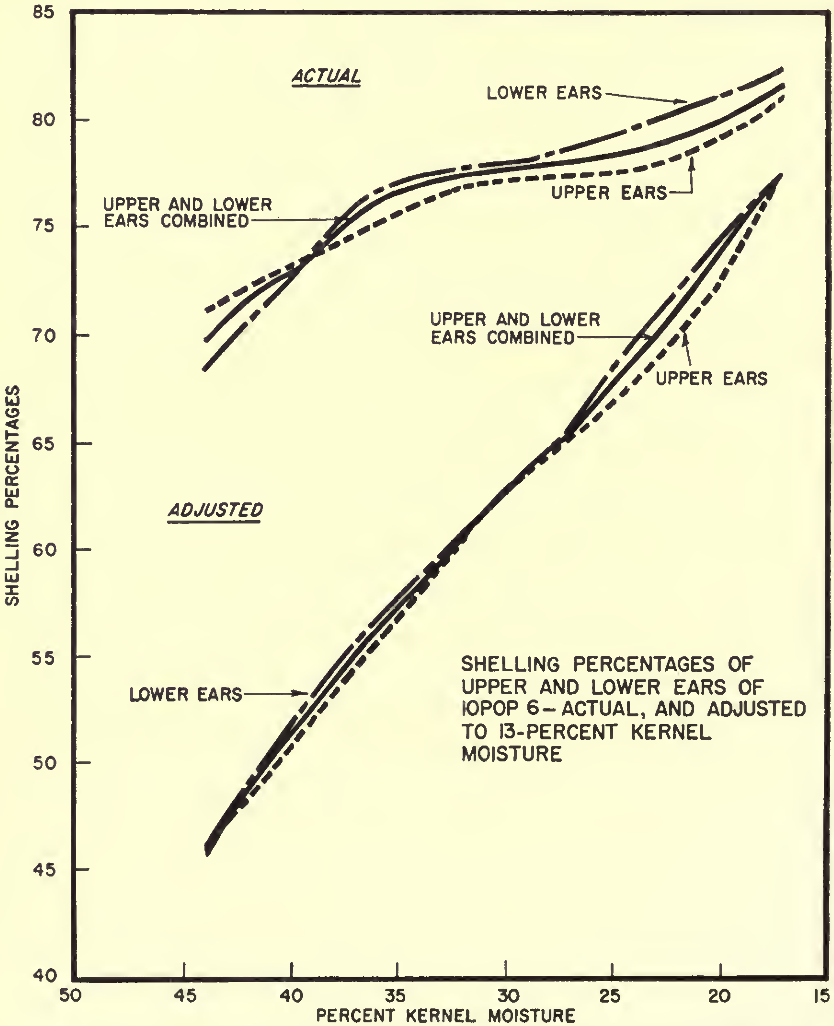
Hybrids like Purdue 202, which produce only one ear, present no problem. In contrast, Iopop 6 produces a variable number of second ears. Eldredge and Thomas (10) show that Purdue 202 produced an average of 101 ears per 100 stalks in 1953, 1954, and 1955, and Iopop 6 produced an average of 135 ears per 100 stalks during the same period. Since lower ears are usually smaller than upper ears, it is often assumed that their shelling percentage is lower. The calculated curves in Fig. 9 show that this assumption was true only when the kernel moisture exceeded 40 percent. When the shelling percentages were adjusted to 13-percent kernel moisture, the lower ears had the same or a slightly better shelling percentage at all kernel moistures than the upper ears.

From corn cribs

Miles and Remmenga (16) observed that the curve showing the relationship between kernel and cob moistures in dent corn taken directly from the field differed from the curve showing the relationship after two weeks' storage in a corn crib. The cribbed corn had a lower cob moisture at between 22- and 11-percent kernel moisture than the corn harvested from the field. There were similar differences in kernel moisture. It follows that dent corn harvested from the field at anywhere between 22- and 11-percent kernel moisture will have a different shelling percentage than corn with equivalent kernel moisture removed from the crib.

In order to determine whether this hypothesis applies to popcorn, Iopop 6 and Purdue 202 were each harvested twice at different moisture levels and placed in four outdoor cribs as previously described. Weekly samples were taken from the cribs between October 3 and December 26, 1956. These were checked against controls harvested from the field. The results (Tables 2 and 3) show that during the dry period between September 24 and October 10 the cribbed corn lost moisture at a more rapid rate than the standing corn; but by October 17 they were alike. Moderate rains started October 25, followed by numerous fogs. This weather increased both kernel and cob moistures, but there were no consistent differences between the cribbed corn and

the corn remaining in the field (Tables 2 and 3). Consequently, shelling percentages were alike. Unlike corn in the field, ear corn stored under shelter is not subject to the wide variations of late fall weather. Therefore, corn standing in the field would have a higher kernel and cob moisture content because popcorn absorbs moisture from the air at a relatively rapid rate (12).



Shelling percentages of upper and lower ears of Iopop 6 at harvest, 1955: (1) calculated on the actual kernel-moisture basis; and (2) adjusted to 13-percent kernel moisture. (Fig. 9)

FACTORS AFFECTING POPPING EXPANSION

In addition to the actual moisture content of the kernels when popped, the morphological development or maturity of the kernels seems to have an important effect on popping expansion. In preliminary work Bemis and Huelsen (4) found that since the dry weights of cobs remained constant, the cobs were fully mature on the basis of constant dry weight by the time the kernels had reached 50-percent moisture content. The cobs did not lose moisture until the kernel moistures fell below 30 percent. The kernels accumulated dry matter until they reached 30-percent moisture, after which the cobs lost moisture more rapidly than the kernels. Dry matter or dry weights of the kernels were closely related to popping expansion, the pooled correlation coefficient being 0.976.

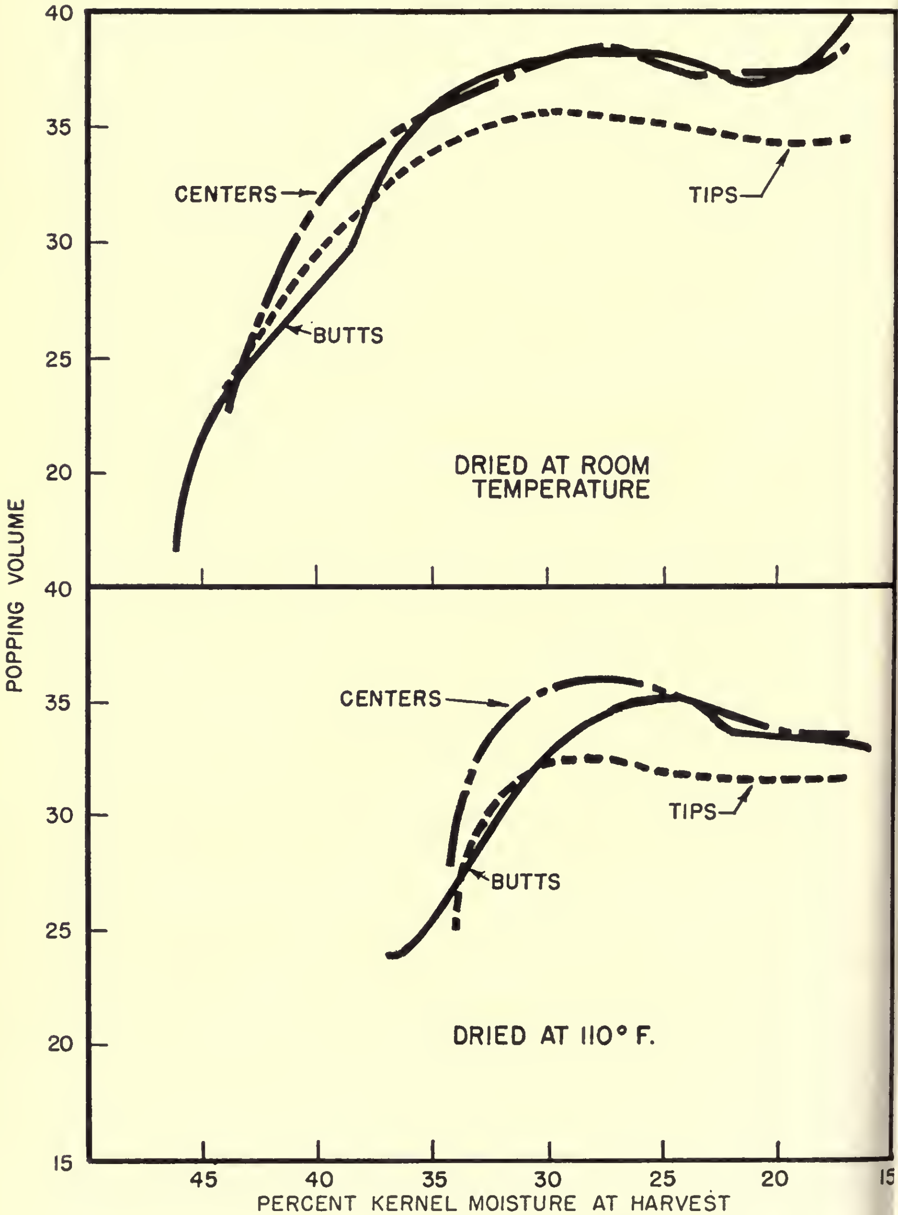
Effect of Harvest Moisture

During the experiments previously discussed it became apparent that popcorn reached its maximum popping expansion at a relatively early stage of maturity. Thus Huelsen and Bemis (13) found that Iopop 6 and Purdue 202 could be considered fully mature on the basis of maximum popping expansion when the kernels reached 35- to 30-percent moisture. This conclusion is consistent with the results obtained by Kiesselbach (15) with dent corn. He found that translocation from the plant to the kernels had been completed 50 days after silking, at which time the kernels were too hard to be readily dented with the thumbnail and the kernel and cob moistures had reached 34 and 53 percent respectively.

The 1954 harvests showed that maximum popping expansion was reached between 35- and 30-percent kernel moisture at harvest. A slight decline in expansion occurred in subsequent harvests, but no adequate explanation for this trend was found.

In 1955 the ears were harvested in the same way except that separate records were kept on butt, center, and tip sections of the ears. The ears were dried at room temperatures and at 110° F. The curves for both Iopop 6 and Purdue 202 were calculated, but only those for Purdue 202 are shown in Fig. 10. The maximum popping expansions of both hybrids coincided with the 30- to 25-percent moisture range, after which they decreased slightly as in 1954.

In general, the center sections of the ears had the highest popping expansions and the tip sections the lowest. The butt sections were intermediate except when the kernel harvest moistures exceeded 38 percent.



Popping expansion of Purdue 202 in relation to butt, center, and tip sections, percent kernel moisture at harvest, and method of drying, 1955. (Fig. 10)

The 1954 experiments were repeated in 1956, but neither the dry weights per kernel nor the popping expansions in Table 7 show any trend. The 1956 harvest season was almost completely rain-free and lasted only 28 days as compared with 52 days and 53 days in 1954 and 1955 respectively. Although the moisture loss per day from the ears was highest in 1956 (Table 4), the average popping expansion for the harvests below 30-percent kernel moisture were practically the same as in 1954 and 1955 (Table 8).

The 1956 results (Table 7) again showed that harvesting popcorn at about 30-percent kernel moisture had no adverse effect on popping expansion. The principal respect in which the 1956 results differ from those obtained in 1954 and 1955 is in the absence of a decline in popping expansion following a peak that varied from 33- to about 25-percent kernel moisture at harvest.

Table 7. — Popping Expansion and Dry Weights per Kernel as Related to Kernel Moisture at Harvest, 1956

Iopop 6			Purdue 202		
Percent kernel moisture at harvest	Dry weight per kernel (mg.)	Popping expansion (volumes)	Percent kernel moisture at harvest	Dry weight per kernel (mg.)	Popping expansion (volumes)[a]
35.3	95.0	36.8	36.1	139.2	36.3
33.2	96.9	34.6	32.6	138.0	37.2
32.9	101.0	37.2	31.5	144.3	36.3
32.6	95.6	35.0	29.4	139.1	36.8
27.8	98.3	35.5	28.3	145.8	36.3
26.2	104.3	36.3	24.1	138.8	35.5
23.8	98.1	37.2	21.5	142.3	35.5
20.3	97.7	35.9	18.0	141.1	37.2
20.2	102.6	37.2	17.5	141.8	38.5
17.7	102.2	36.8	16.8	145.3	37.6
17.1	107.4	36.8	15.4	144.8	37.2
16.8	101.5	35.9	14.0	142.8	37.6
14.0	99.9	36.3	13.7	141.5	37.6
12.1	102.0	36.8	13.0	143.5	37.6
10.1	104.1	37.2	10.2	142.0	38.0
Average[b]	101.6	36.5		142.4	37.1
$S.E.\bar{x}$[b]	.82	.03		.41	.07

[a] All samples were reconstituted with water to 12.5-percent kernel moisture.
[b] For kernels below 30-percent harvest moisture.

The correlation coefficients for the 1955 data were computed independently for butt, center, and tip sections, and were separated into three kernel moisture groups (Table 9). For popcorn dried at room temperatures, the correlations between popping expansion and kernel moistures 34 percent or above were very high. Between 33- and 30-percent kernel moisture the coefficients varied widely, and only one was significant at the 5-percent level. This coefficient of 0.967 would indicate a significant relation between increased kernel moisture and increased popping expansion in Iopop 6 butt sections, except that it was based on only four degrees of freedom. Under these circumstances,

Table 8. — Average Dry Weight per Kernel and Popping Expansion of Iopop 6 and Purdue 202 Below 30-Percent Kernel Moisture at Harvest

(Dry Weights per cob are for entire moisture range at harvest)

Part of ear tested	Dry weights		Popping expansion	
	Per kernel (mg.)	Per cob (gm.)	Total volumes	Cu. in. per 100 mg.[a]
1954 Average				
Iopop 6				
Entire upper ear	104.5 ± .56	14.7 ± .14	35.5 ± .17	.261
Butts	....	....	....	....
Centers	....	....	....	....
Tips	....	....	....	....
Entire lower ear	....	....	....	....
Purdue 202				
Entire ear	153.6 ± .94	22.8 ± .16	38.5 ± .17	.284
Butts	....	....	....	....
Centers	....	....	....	....
Tips	....	....	....	....
1955 Average				
Iopop 6				
Entire upper ear	94.7 ± .60	14.9 ± .10	35.6 ± .24	.264
Butts	106.6 ± .73	6.1 ± .09	35.5 ± .30	.261
Centers	95.8 ± .59	5.1 ± .04	35.4 ± .30	.261
Tips	79.1 ± .62	3.7 ± .06	33.5 ± .25	.247
Entire lower ear	93.2 ± 1.11	9.5 ± .20	34.2 ± .69	.254
Purdue 202				
Entire ear	138.8 ± .79	21.3 ± .10	37.8 ± .23	.281
Butts	150.4 ± .85	9.1 ± .07	37.8 ± .20	.279
Centers	142.0 ± .72	6.9 ± .05	37.9 ± .22	.279
Tips	122.2 ± .85	5.3 ± .06	34.7 ± .22	.256
1956 Average				
Iopop 6				
Entire upper ear	100.4 ± .91	14.4 ± .28	36.5 ± .17	.269
Butts	....	....	....	....
Centers	....	....	....	....
Tips	....	....	....	....
Entire lower ear	....	....	....	....
Purdue 202				
Entire ear	142.4 ± .64	20.0 ± .26	37.1 ± .26	.273
Butts	....	....	....	....
Centers	....	....	....	....
Tips	....	....	....	....

[a] Popping volume in cubic inches per 100 mg. of kernels, water-free basis. All samples were reconstituted with water to 12.5-percent kernel moisture.

significance at the 5-percent level was open to question. Below 30-percent kernel moisture none of the coefficients was significant. The coefficients in Table 9 indicate that popping volumes increase significantly down to 34-percent kernel moisture at harvest. Later maturities did not have any significant effect.

The lower or second ears of Iopop 6 showed the same relationships between kernel moisture at harvest and popping expansion as the upper ears and the ears of Purdue 202 (Fig. 10). The only difference seemed to be in the slightly later stage of maturity at which the kernels of the Iopop 6 lower ears gave the greatest popping expansion. Both upper and lower ears were characterized by decreased popping expansions as the kernel moistures dropped below 25 percent.

Effect of Artificial Drying

Huelsen and Thompson (11) dried popcorn at 100, 110, 120, and 130° F. and found that none of these four drying temperatures had a definitely adverse effect on popping expansion. Huelsen and Bemis (13) showed definite reductions in popping expansion when

Table 9. — Correlations Among the Three Variables — Kernel Moisture at Harvest, Popping Volume, and Dry Weight per Kernel, 1955

Correlated variables	Correlation coefficients		
	Butt sections	Center sections	Tip sections
A. Iopop 6 dried at room temperature			
Percent moisture at harvest × popping volume			
1. 34% and above kernel moisture at harvest	−.900*	−.981**	−.978**
2. 30-33% kernel moisture at harvest	.967*	.388	−.156
3. Below 30% kernel moisture at harvest	.388	.281	.384
Dry weight per kernel × popping volume			
4. 34% and above kernel moisture at harvest	.982**	.986**	.983**
5. 30-33% kernel moisture at harvest	−.575	.837	.824
6. Below 30% kernel moisture at harvest	.325	.298	.438
Percent moisture at harvest × dry weight per kernel			
7. 34% and above kernel moisture	−.937**	−.992**	−.978**
8. 30-33% kernel moisture at harvest	−.364	.174	−.672
9. Below 30% kernel moisture at harvest	.572*	.388	.618*
B. Purdue 202 dried at room temperature			
Percent moisture at harvest × popping volume			
1. 34% and above kernel moisture at harvest	−.959**	−.956**	−.944**
2. 30-33% kernel moisture at harvest	.367	−.240	.971
3. Below 30% kernel moisture at harvest	−.186	−.297	−.035
Dry weight per kernel × popping volume			
4. 34% and above kernel moisture at harvest	.975**	.983**	.897**
5. 30-33% kernel moisture at harvest	−.283	.142	−.813
6. Below 30% kernel moisture at harvest	.196	−.253	.303
Percent moisture at harvest × dry weight per kernel			
7. 34% and above kernel moisture at harvest	−.946**	−.948**	−.935**
8. 30-33% kernel moisture at harvest	−.996	−.995	−.650
9. Below 30% kernel moisture at harvest	.366	.349	.488
C. Iopop 6 dried at 110° F.			
Percent moisture at harvest × popping volume			
1. 30-35% kernel moisture at harvest	−.894*	−.918**	−.963**
2. 25-29% kernel moisture at harvest	−.567	−.779	−.882
3. Below 25% kernel moisture at harvest	−.278	.376	0
Dry weight per kernel × popping volume			
4. 30-35% kernel moisture at harvest	.865	.873*	.957**
5. 25-29% kernel moisture at harvest	−.505	.615	.092
6. Below 25% kernel moisture at harvest	.118	.352	.421
Percent moisture at harvest × dry weight per kernel			
7. 30-35% kernel moisture at harvest	−.790	−.875*	−.847*
8. 25-29% kernel moisture at harvest	.307	−.192	.215
9. Below 25% kernel moisture at harvest	.564	.483	.298
D. Purdue 202 dried at 110° F.			
Percent moisture at harvest × popping volume			
1. 30-35% kernel moisture at harvest	−.868	−.794	−.679
2. 25-29% kernel moisture at harvest	−.452	.303	.556
3. Below 25% kernel moisture at harvest	.077	−.265	−.046
Dry weight per kernel × popping volume			
4. 30-35% kernel moisture at harvest	.695	.658	.468
5. 25-29% kernel moisture at harvest	.753	.411	.894
6. Below 25% kernel moisture at harvest	.601	.325	.227
Percent moisture at harvest × dry weight per kernel			
7. 30-35% kernel moisture at harvest	−.751	−.639	−.642
8. 25-29% kernel moisture at harvest	−.889	−.301	.830
9. Below 25% kernel moisture at harvest	−.178	−.032	.161

* Significant.
** Highly significant.

popcorn of various maturities was dried at 110° F. However, these reductions became progressively smaller as maturity advanced; and when the kernel moisture dropped below 25 percent, there were no appreciable decreases in popping expansion due to drying with forced air at 110° F.

Additional experiments in 1955 with Iopop 6 and Purdue 202 showed that the popping expansions of identical lots of popcorn dried at room temperature and at 110° F. increased as maturity advanced. After reaching a peak, the popping expansions declined slightly. The maximum popping expansion of room-dried corn was attained around 30-percent kernel moisture at harvest regardless of ear section. When the corn was dried at 110° F., the maximum varied, depending upon the ear part. Butt and center sections of both hybrids reached a maximum slightly over 25-percent kernel moisture at harvest. The tip sections of Purdue 202 fell within this range, but the tip sections of Iopop 6 reached the maximum popping expansion around 23-percent kernel moisture at harvest.

Taking into account the necessary moisture differential at harvest, the results for Purdue 202 (Fig. 10) and Iopop 6 showed that room-dried popcorn popped slightly better than popcorn dried at 110° F. These results confirmed the feasibility of artificial drying as reported by Huelsen and Bemis (13).

In 1956 further experiments were conducted on a somewhat different plan. Popcorn was harvested at two different dates (Table 10) and treated three different ways: placed in cribs and sampled periodically; dried at room temperatures; and dried at 110° F. The two hybrids were left in the field and sampled periodically (Tables 2 and 3). One of these harvests was selected on November 7 when the corn was fully mature (Table 10). The November 7 field harvests popped about the same as the room-dried samples and those taken from the cribs on the same day. The popping expansions of the lots dried at 110° F. were slightly lower, but exceeded 35 volumes according to the old scale.

Effect of Low Temperatures

It is generally believed that freezing is highly injurious to popping expansion. Eldredge (7) states that popcorn exposed to temperatures of 20° F. or lower may pop too poorly to be salable. Huelsen and Bemis (13) harvested Iopop 6 and Purdue 202 at different kernel moistures and chilled both varieties of husked ears for 24 hours at 35° F. The ears of each variety were divided into two lots. Each lot was dried either at room temperatures or 110° F. Comparisons with controls showed that chilling had no adverse effect on popping. Addi-

Table 10. — Comparison of Popping Expansions of Iopop 6 and Purdue 202 Matured in the Field, Stored in Outdoor Corn Cribs, Dried at Room Temperature, and Dried at 110° F.

Variety	Date harvested	Directly from field: Percent moisture at harvest		Directly from field: Popping expansion[a] (cu. in. per lb.)	From corn cribs: Percent moisture when sampled		From corn cribs: Popping expansion[a] (cu. in. per lb.)	Dried at room temperature: Percent moisture after drying		Dried at room temperature: Popping expansion[a] (cu. in. per lb.)	Dried at 110° F.: Percent moisture after drying		Dried at 110° F.: Popping expansion[a] (cu. in. per lb.)
		Kernels	Cobs		Kernels	Cobs		Kernels	Cobs		Kernels	Cobs	
Iopop 6	Sept. 24[b]	27.8	45.4					10.2		1112			
	Nov. 7	12.6	12.5	1125	12.9	12.9	1113				8.0	6.1	1112
Iopop 6	Oct. 3[b]	17.7	28.9					9.6		1100			
	Nov. 7	12.6	12.5	1125	12.5	12.6	1125				10.3	10.0	1025
Purdue 202	Sept. 24[b]	28.3	42.9					9.8		1100			
	Nov. 7	12.5	13.1	1162	12.8	12.9	1112				8.5	6.4	1025
Purdue 202	Oct. 3[b]	16.8	22.3					9.2		1125			
	Nov. 7	12.5	13.1	1162	13.1	13.1	1137				9.6	7.2	1038

[a] Divided by 29.24 to convert to volumes. All samples were reconstituted with water to 12.5-percent kernel moisture.
[b] Controls dried at room temperature. Harvest was also divided into two additional parts; one was placed in cribs and the other dried at 110° F.

tional harvests made at the same time were exposed to −10° F. for periods of 6 hours and 15 hours respectively, and then dried by forced heated air at 80° F. and 110° F. Freezing reduced popping expansion in two lots harvested at 29.65- and 31.00-percent kernel moisture, but two others with 17.55- and 23.40-percent moisture were not injured. Additional tests showed that when kernel moistures reached 20 percent, injuries due to freezing were either absent or negligible.

Since the experiments failed to agree with the statements made by Eldredge (7), additional tests were undertaken in 1956. The data from these tests are summarized in Table 11. The husked ears were placed in open baskets under refrigeration at the temperatures indicated. Only one of the four lots of Iopop 6 — the lot harvested at 23.8-percent kernel moisture — showed any material damage to popping expansion. Compared with the control, the popping expansion of this lot was reduced considerably by 40° below zero and only slightly by 25° F. Purdue 202 was definitely damaged by freezing when harvested at 28.3-percent moisture. At 18.5-percent moisture the damage was very slight, and at 17.5 and 13.7 percent almost no damage occurred. In general, the damage to both hybrids was relatively minor, and even the lowest popping expansion of the lots tested (875 cu. in. per lb., or 30 volumes on the old scale) would be acceptable for commercial use.

Table 11. — Effect on Popping Expansion of Freezing Popcorn Ears at Various Maturities, Followed by Drying at Room Temperature
(Controls also dried at room temperature)

Variety and planting	Kernel moisture at harvest (percent)	Treatment	Popping expansion (cu. in. per lb.)[a]
Iopop 6, first	27.8	Control (not frozen)	1038
	27.8	24 hours at −40° F.	1025
	27.8	24 hours at +25° F.	1050
Iopop 6, first	20.3	Control (not frozen)	1050
	20.3	24 hours at −40° F.	1138
	20.3	24 hours at +25° F.	1112
Iopop 6, second	23.8	Control (not frozen)	1125
	23.8	24 hours at −40° F.	938
	23.8	24 hours at +25° F.	1050
Iopop 6, first	20.2	Control (not frozen)	1088
	20.2	24 hours at −40° F.	1075
	20.2	24 hours at +25° F.	1100
Purdue 202, first	28.3	Control (not frozen)	1062
	28.3	24 hours at −40° F.	912
	28.3	24 hours at +25° F.	962
Purdue 202, first	17.5	Control (not frozen)	1125
	17.5	24 hours at −40° F.	1162
	17.5	24 hours at +25° F.	1125
Purdue 202, second	18.5	Control (not frozen)	962
	18.5	24 hours at −40° F.	925
	18.5	24 hours at +25° F.	875
Purdue 202, first	13.7	Control (not frozen)	1100
	13.7	24 hours at −40° F.	1138
	13.7	24 hours at +25° F.	1125

[a] Divide by 29.24 to convert to volumes. All samples were reconstituted with water to 12.5-percent kernel moisture.

Although the two separate experiments fail to agree with statements made by Eldredge (7), this fact does not mean that he is wrong. Assuming that frost or freezing alone may not be the only factor affecting popping expansion, Iopop 6 and Purdue 202 were left in the field and harvested once a week between October 17 and December 26, 1956. The kernel moistures reached 10 percent by October 17, and then gradually increased until they reached 16 to 17 percent by December 26 (Tables 2 and 3). Each harvest was placed in mesh bags and hung in an unheated attic. The controls consisted of two harvests as shown in Table 12. The field-harvested lots reached their peak popping volumes in late October and remained more or less static until late December. Iopop 6 showed a greater tendency to decline than Purdue 202. The controls reached their peaks early in November, and tended to decline thereafter. It is obvious that the popcorn left in the field did not deteriorate any more than that stored in cribs, but it should be noted that the rainfall in November and December was fairly light (see Tables 2 and 3).

Table 12. — Popping Expansions of Popcorn Left in the Field Compared With Controls Sampled From Corn Cribs, 1956

In field until harvested			Popping expansion of controls from corn crib (cu. in. per lb.)[a]	
Date harvested	Percent kernel moisture at harvest	Popping expansion[a] (cu. in. per lb.)	Harvested Sept. 24, kernel moisture high[b]	Harvested Oct. 3, kernel moisture low[b]
		Iopop 6		
Oct. 3	17.7	1075		
10	17.1	1075	1112	1075
17	10.1	1088	1100	1100
24	11.4	1125	1075	1088
31	12.1	1125	1100	1088
Nov. 7	12.6	1125	1112	1125
14	12.2	1100	1100	1138
21	13.1	1125	1075	1088
28	12.8	1100	1075	1050
Dec. 5	13.0	1125	1075	1062
12	14.5	1050	1088	1100
19	15.9	1012	962	1075
26	16.9	1050	987	1075
		Purdue 202		
Oct. 3	16.8	1100		
10	13.0	1100	1062	1075
17	10.2	1112	1125	1088
24	11.1	1138	1062	1125
31	11.8	1138	1088	1050
Nov. 7	12.5	1162	1112	1138
14	11.9	1150	1125	1162
21	12.6	1150	1088	1100
28	12.6	1175	1088	1125
Dec. 5	13.1	1188	1100	1112
12	14.8	1112	1112	1150
19	15.2	1125	1050	1100
26	16.5	1088	988	1062

[a] Divide by 29.24 to convert to volumes. All samples were reconstituted with water to 12.5-percent kernel moisture.
[b] September 24 and October 3 harvest moistures of Iopop 6 kernels were 27.8 and 17.7 percent respectively, and 28.3 and 16.8 percent for Purdue 202.

Effect of Alternate Wetting and Drying

Since low temperatures alone and moderate rainfall such as prevailed in 1956 seemed to have only a slight effect on popping expansion, an experiment was set up to simulate the normal weather conditions in late October and in November. A single harvest of each of the two hybrids, Iopop 6 and Purdue 202, was used for the controls as well as for the treatments. The controls were dried in mesh bags in an unheated attic. The treatments consisted of immersing the ears in water for various periods of time up to two hours. The soaked ears were then placed in boxes, covered with wet burlap sacks, and put in cold storage at 35° F. for 24 hours. They were then placed in the dryer described by Huelsen and Bemis (13) and dried by means of unheated forced air for the periods shown in Table 13. Samples sufficiently large for moisture testing and popping were shelled after drying and stored in glass jars. The remaining ears were used to complete another cycle of soaking, cold storage, and drying until nine cycles had been completed. All samples were adjusted to 12.5-percent moisture before popping.

The popping expansion of Iopop 6 was not affected by the treatments until the sixth cycle had been completed (Table 13). The behavior of Purdue 202 was different. Popping expansion decreased after

Table 13. — Effect on Popping Expansion of Alternately Soaking Ears and Drying Them by Forced Air at Room Temperature, 1956

Cycle	Percent kernel moisture[a]			Hours dried	Mg. dry weight per kernel	Popping expansion (cu. in. per lb.)[b]
	Before soaking	After soaking	After drying			
		Iopop 6				
Control	9.2				102.2	1075
First	9.2	12.6	10.0	23.0	102.6	1050
Second	10.0	16.8	11.2	23.2	102.1	1062
Third	11.2	21.2	12.0	24.0	96.8	1075
Fourth	12.0	22.6	14.4	25.0	96.3	1044
Fifth	14.4	27.6	12.6	23.0	99.2	1050
Sixth	12.6	26.5	10.8	49.0	101.2	1025
Seventh	10.8	27.4	10.0	65.0	100.3	988
Eighth	10.0	26.4	9.5	47.2	101.8	950
Ninth	9.5	24.0	8.6	48.8	97.8	850
		Purdue 202				
Control	8.9				145.3	1100
First	8.9	13.5	10.8	23.2	138.2	1050
Second	10.8	18.3	12.7	24.0	144.9	1038
Third	12.7	22.3	14.2	25.0	135.6	969
Fourth	14.2	26.2	16.2	23.0	144.1	1031
Fifth	16.2	30.1	13.0	49.0	138.8	1000
Sixth	13.0	28.9	11.6	65.0	140.5	938
Seventh	11.6	28.6	10.5	47.2	139.6	925
Eighth	10.5	26.0	9.4	48.8	138.6	875
Ninth	9.4	25.2	9.1	117.0	141.3	812

[a] Kernel moisture at harvest was 17.7 percent for Iopop 6 and 16.8 percent for Purdue 202. Controls came from same lots as the soaked treatments.

[b] Divide by 29.24 to convert to volumes. All samples were reconstituted with water to 12.5-percent kernel moisture.

each of the first three cycles. For some reason it increased again after the fourth cycle, followed by successive decreases. The wetting followed by low temperatures and then drying seem to be the factors that reduce popping expansion. It should be noted that freezing was not involved, the treatments merely attempting to simulate the October-November weather frequently occurring at Urbana.

After the first few soakings the kernels became discolored and the cobs assumed a soggy, water-soaked appearance. There was no evidence of mold or bacterial breakdown. All of the Iopop 6 treatments popped normally; but beginning with the sixth cycle, the Purdue 202 hulls (pericarps) broke loose during popping — a condition that would be highly desirable if it could be attained without impairing popping expansion.

Effect of Kernel Development

The generally accepted method of determining maturity is by means of kernel moistures at harvest, and the grower assumes that his crop is ripe when the kernel moisture drops below 20 percent. This assumption is incorrect in two respects. First, this study has shown that popcorn is mature when the kernel moisture reaches 30 percent, and Kiesselbach (15) has shown that dent corn is mature when the kernel moisture reaches 34 percent. Second, it is false to assume that moisture content of the kernels is the true criterion of maturity when this term is taken to mean full morphological development. Under certain conditions the stalk dies prematurely, thus stopping translocation, which, in turn, inhibits full development of the kernels. The moisture content of these kernels may be at the optimum for popping, but popping expansion will be below normal. In extreme cases the kernels are noticeably smaller, but otherwise their appearance is normal.

During the three-year period (1954-1956) covered by these experiments, all but one planting of popcorn developed normally. No frost damage occurred in any of the three years. The underdeveloped lot was planted June 14, 1956, on high ground. A combination of dry weather (Table 4) and severe European corn borer damage caused premature drying of the stalks and lack of proper kernel development. This condition was especially noticeable in Purdue 202. Both Iopop 6 and Purdue 202 were harvested, and before shelling, the ears were sorted into classes according to kernel development.

The better developed ears had a higher kernel moisture content, a higher dry weight per kernel, and a higher popping expansion than the less well-developed ears. The extent of the underdevelopment of the kernels (Table 14) is apparent when the dry weights are compared with

Table 14. — Kernel Development of Iopop 6 and Purdue 202 Popcorn in Relation to Kernel Dry Weight and Popping Expansion, 1956

Moisture at harvest (percent)	Kernel development	Dry weight per kernel (mg.)	Popping expansion[a]	
			Cu. in. per lb.	Volume equivalent
	Iopop 6			
21.9	fair	92.6	1125	38.5
20.1	poor	83.3	1062	36.0
	Purdue 202			
16.4	poor	108.7	1012	35.0
16.3	very poor	100.0	925	32.0
14.0	extremely poor	84.5	788	27.0

[a] All samples were reconstituted with water to 12.5-percent kernel moisture.

those for the more normally developed kernels (Table 8). The surprising part of the data in Table 14 is the fairly high popping expansion of the poorly developed ears. Only the Purdue 202 ears with "extremely poor" kernel development popped below the trade standard of 30 volumes. It is obvious that the popping expansion of poorly developed popcorn can be improved either by sorting out the substandard ears or by rigorous control of the milling process.

Effect of Dry Weight per Kernel

Proper development of the kernel is usually necessary to insure maximum popping expansion. As mentioned in the previous section, the kernel is fully developed or mature when the storage of nutrients is complete. This point is characterized by no further gains in dry weight. In preliminary work, Bemis and Huelsen (4) showed that no further gains in dry weight occurred after the kernel moisture reached 30 percent. A great deal of additional work has been done subsequently on the problem of ear maturity.

For all practical purposes there were no changes in dry weight per kernel of Iopop 6 when the moisture fell below 27 percent in 1954. At this point the dry weight of 105.0 mg. was equal to the average of 104.5 mg. (Table 15). In Purdue 202 the kernel dry weight reached 153.5 mg. at 28.1-percent moisture, equalling the average of 153.6 mg.

When harvesting started in 1954, the cob moistures were 53.8 and 49.0 percent for Iopop 6 and Purdue 202 respectively (Table 15). But it should be noted that the changes in dry weight per cob were very minor, indicating that the cobs attained full maturity much sooner than the kernels.

More detailed studies in 1955 showed very similar results (Tables 16 and 17). Excluding minor variations, the dry weights per kernel of

Table 15. — Relation Between Moisture at Harvest, Dry Weight, and Popping Expansion of Iopop 6 and Purdue 202 Dried at Room Temperature, 1954

Iopop 6					Purdue 202				
Kernels		Cobs			Kernels		Cobs		
Percent moisture at harvest	Dry weight per kernel (mg.)	Percent moisture at harvest	Dry weight per cob (gm.)	Popping expansion[a] (volumes)	Percent moisture at harvest	Dry weight per kernel (mg.)	Percent moisture at harvest	Dry weight per cob (gm.)	Popping expansion[a] (volumes)
49.6	58.0	53.8	14.6	14.5	48.3	95.5	49.0	21.1	22.5
42.5	72.0	52.3	14.1	25.5	43.5	121.5	47.0	22.5	30.8
41.4	87.5	48.0	14.5	27.8	41.6	122.5	46.3	22.4	31.0
41.2	81.5	50.8	14.4	26.5	41.2	131.5	47.4	21.6	34.0
36.1	94.5	49.3	14.2	33.0	37.6	139.5	46.7	23.1	35.0
34.9	93.0	48.7	15.0	35.0	33.9	148.0	47.5	23.0	39.0
33.5	96.5	49.3	14.6	35.0	32.1	146.0	48.1	22.4	38.5
30.9	99.5	48.2	15.2	36.8	31.4	150.5	49.0	22.6	39.2
29.8	103.0	48.6	14.7	35.2	30.6	149.0	48.6	22.8	40.0
27.0	105.0	46.9	14.8	36.0	28.1	153.5	44.9	23.0	38.5
23.4	106.5	40.3	14.0	35.5	26.5	152.5	45.2	22.8	39.2
23.1	101.0	40.4	14.4	36.0	24.9	155.0	43.0	22.5	37.5
22.8	103.5	41.5	14.1	35.8	23.3	152.5	41.8	22.7	38.2
18.1	104.5	32.1	13.8	34.8	22.6	155.5	38.5	22.8	37.2
17.1	106.0	24.3	14.8	35.5	21.3	152.0	36.6	22.4	38.2
16.4	104.0	23.0	13.8	34.8	19.9	154.5	33.2	24.0	38.5
15.2	103.5	20.2	15.9	36.0	19.8	159.5	33.7	23.4	38.0
14.8	107.5	19.3	15.0	35.0	18.0	151.5	27.0	22.4	39.2
14.8	100.0	16.1	15.6	36.0	17.7	158.0	28.7	24.0	37.8
14.3	104.0	17.6	15.8	34.5	17.5	155.5	25.3	23.4	39.2
14.0	105.5	16.7	13.8	36.0	17.5	147.0	27.2	22.9	38.5
14.0	104.5	15.6	15.8	36.5	17.1	148.0	24.8	22.6	38.5
13.8	107.5	16.3	15.4	34.2	16.6	154.5	22.4	24.6	38.0
Average	104.5 ± .56[b]		14.7 ± .14	35.5 ± .17[b]		153.6 ± .94[b]		22.8 ± .16	38.5 ± .17[b]

[a] All samples were reconstituted with water to 12.5-percent kernel moisture.
[b] Includes only those below 30-percent kernel moisture.

Table 16. — Relation Between Moisture at Harvest, Dry Weight, and Popping Expansion of Iopop 6 Dried at Room Temperature, 1955

(Upper and lower ears paired with reference to date of harvest)

Upper ears					Lower ears				
Kernels		Cobs			Kernels		Cobs		
Percent moisture at harvest	Dry weight per kernel (mg.)	Percent moisture at harvest	Dry weight per cob (gm.)	Popping expansion (volumes)[a]	Percent moisture at harvest	Dry weight per kernel (mg.)	Percent moisture at harvest	Dry weight per cob (gm.)	Popping expansion (volumes)[a]
44.2	71.2	53.4	14.7	24.8	42.8		56.6	10.3	21.2
43.8	67.5	53.8	12.8	21.5	45.2		61.6	11.2	21.0
41.0	77.2	50.4	15.0	27.5	43.2		60.8	9.6	24.2
36.6	84.0	51.0	14.9	32.5	39.2		59.2	6.9	
34.6	89.4	49.6	15.1	34.8	36.8		55.0	8.8	32.0
33.8	94.3	49.8	15.4	36.8	37.0		54.4	9.6	32.2
32.4	92.8	50.6	14.7	35.3	32.8	91.7	55.4	10.3	34.8
32.0	97.7	50.4	15.4	37.0	31.0	95.4	55.6	10.0	34.8
31.8	93.8	50.4	14.8	36.8	30.8	92.1	57.6	10.6	33.8
30.0	95.6	50.8	15.4	35.5	30.2	94.8	52.0	10.0	34.2
27.8	97.3	47.0	15.5	37.3	25.4	94.6	48.4	9.9	34.5
26.4	98.0	45.6	15.3	35.3	28.0	91.1	53.0	9.1	34.5
26.2	96.0	45.2	15.0	35.8	28.0	97.7	52.4	9.1	34.0
25.0	97.5	44.4	14.7	36.5	26.0	97.6	49.4	9.9	35.8
23.0	96.0	43.2	15.7	35.8	24.8	96.6	47.8	9.6	34.8
22.6	91.3	38.6	14.9	34.8	23.6	99.0	43.6	10.0	35.2
21.0	93.7	35.6	15.2	32.5	21.2	96.4	37.0	8.1	34.0
21.0	95.3	36.2	15.0	35.5	19.2	93.7	30.8	10.6	34.0
20.4	93.4	30.0	14.7	35.5	22.0	89.8	43.0	7.8	34.0
19.4	93.7	27.2	14.2	34.5	17.8	87.1	25.4	7.7	34.0
19.0	96.4	30.0	15.0	35.0	19.4	94.4	34.2	10.1	34.5
18.4	90.6	26.0	15.1	35.5	17.4	90.2	20.8	9.4	33.8
18.4	91.1	23.8	15.0	36.3	18.6	85.1	25.0	9.7	32.0
17.0	94.3	23.8	15.1	35.5	18.8	92.6	33.4	9.2	33.8
Average	$94.7 \pm .60$[b]		$14.9 \pm .10$	$35.6 \pm .24$[c]		93.2 ± 1.11[b]		$9.47 \pm .20$	$34.2 \pm .69$[b]

[a] All samples were reconstituted with water to 12.5-percent kernel moisture.
[b] Including only those below 30-percent kernel moisture.
[c] Including only those below 35-percent kernel moisture.

Iopop 6 did not increase after the kernel moisture reached 32.0 percent for upper ears (Table 16) and 28.0 percent for lower ears.

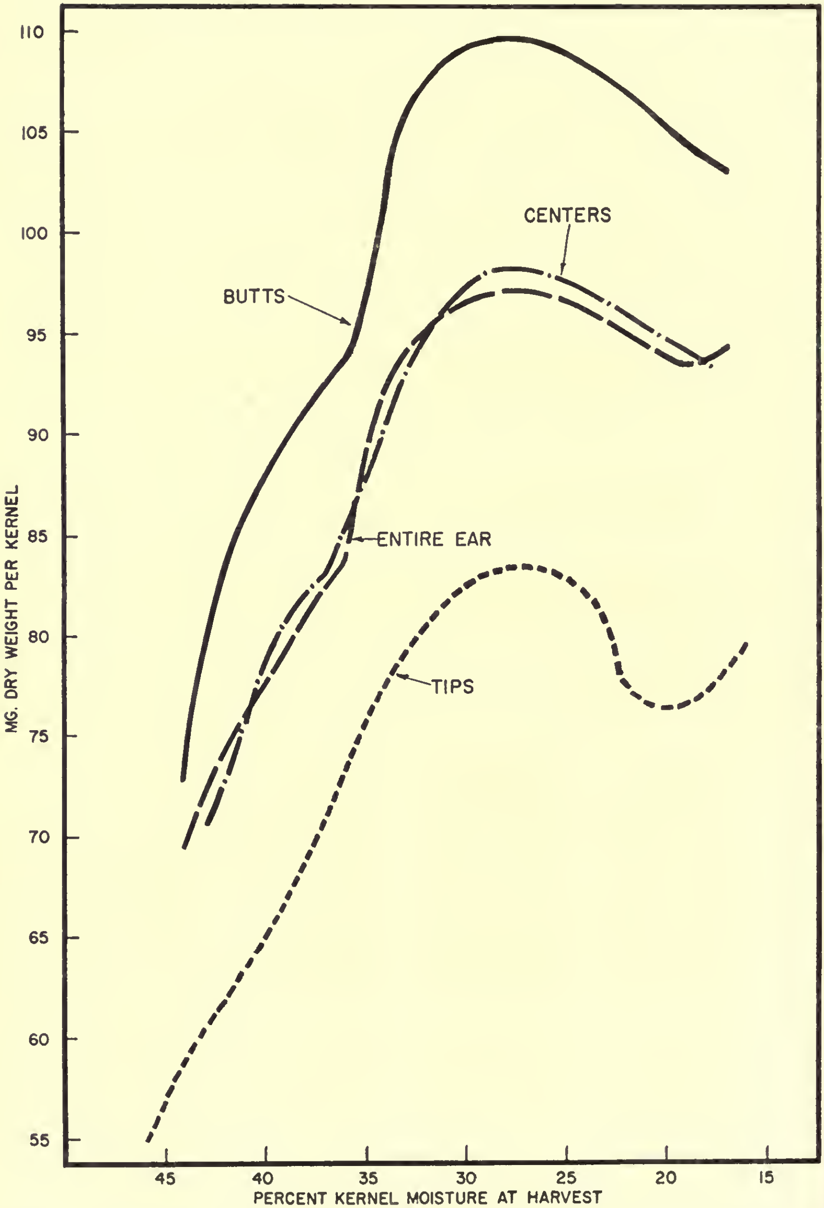
The estimated curves for the two hybrids were plotted by ear section and by entire ear; but since the curves were quite similar, only those for Iopop 6 upper ears are shown in Fig. 11. The maximum kernel dry weights for the entire ear were reached between 30- and 25-percent kernel moisture at harvest. These dry weights were practically the same as those for the center section. As might be expected, the dry weight per kernel was highest for the butt sections and lowest for the tip sections, reflecting the larger kernels found at the butts and the smaller kernels at the tips. Each of the three sections showed parallel trends.

The correlations between kernel moisture at harvest and dry weight per kernel for room-dried ears of Iopop 6 and Purdue 202 were calculated by ear section for three moisture groups: above 34 percent; 33 to 30 percent; and below 30 percent (A and B, Table 9). As would be expected from Fig. 11, corn harvested with a moisture content above 34 percent had highly significant correlation coefficients (A-7, B-7, Table 9).

Table 17. — Relation Between Moisture at Harvest, Dry Weight, and Popping Expansion of Purdue 202 Dried at Room Temperature, 1955

Kernels		Cobs		Popping expansion (volumes)[a]
Percent moisture at harvest	Dry weight per kernel (mg.)	Percent moisture at harvest	Dry weight per cob (gm.)	
44.8	101.6	48.6	21.8	22.8
43.8	108.8	48.8	20.8	25.8
40.4	122.6	46.2	21.0	32.5
36.6	127.2	47.6	21.5	35.3
34.8	128.4	45.4	20.9	36.0
34.8	137.4	47.8	22.0	36.8
31.2	133.9	46.2	21.0	37.8
30.8	137.6	47.8	21.7	39.8
29.6	141.9	47.2	20.5	38.8
28.2	140.6	45.2	21.5	38.3
27.6	141.2	45.4	21.3	37.5
26.8	144.8	42.0	21.8	38.5
25.0	139.7	41.8	20.6	35.8
24.0	137.3	40.8	21.2	37.8
23.6	138.0	39.8	21.5	37.5
22.0	133.3	34.6	20.5	38.8
20.4	137.0	30.2	21.2	37.8
20.2	134.9	32.8	21.8	37.0
19.0	136.1	27.0	21.6	37.8
18.6	137.4	25.0	20.8	37.3
18.2	138.5	25.2	20.9	38.0
17.6	144.5	26.2	21.9	37.8
16.6	137.4	19.2	21.1	37.5
16.4	138.3	20.2	22.1	39.8
Average	138.8 ± .79[b]		21.3 ± .10	37.8 ± .23[c]

[a] All samples were reconstituted with water to 12.5-percent kernel moisture.
[b] Including only those below 30-percent kernel moisture.
[c] Including only those below 35-percent kernel moisture.

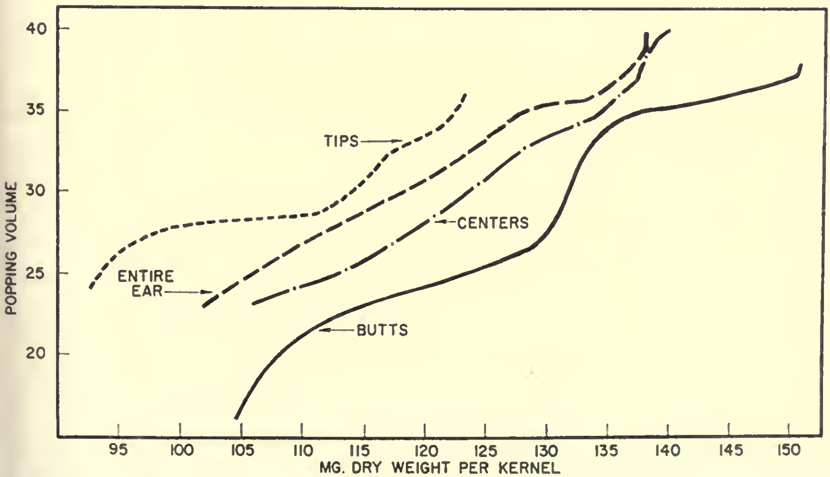


Relation between percent kernel moisture at harvest and dry weight per kernel from butt, center, and tip sections, and from entire upper ears of Iopop 6 (averages of 25 ears, 1955). (Fig. 11)

The lots dried at 110° F. (C-7, D-7, Table 9) showed the same trend, although only two of the six coefficients were significant. None of the coefficients calculated from harvests below 30 percent moisture was significant (C-8, C-9, D-8, D-9).

When the corn was harvested below 30-percent moisture and dried at room temperatures, all six of the coefficients were positive, but only two were significant (A-9, B-9, Table 9), indicating a tendency for dry weights to increase in relation to moisture content. In other words, as moisture decreased, the dry weights per kernel also decreased. The artificially dried Iopop 6 showed the same tendency (C-9), but coefficients for Purdue 202 (D-9) were too small to show any trend.

The correlations between dry weight per kernel and popping expansion for the room-dried lots were all highly significant (A-4, B-4) in Table 9. In contrast, only two of the coefficients for the group harvested between 30- to 35-percent kernel moisture and dried at 110° F. were significant, and they showed a similar trend (C-4, D-4). In more mature ears (lines 5 and 6, A, B, C, D), the correlations of both the room-dried and artificially dried ears were variable and none was significant. The relation between dry weights per kernel and popping volumes were plotted as estimated curves for both hybrids; but since the curves are similar, only those for Purdue 202 are shown in Fig. 12. The different behavior of the three ear sections is of interest.



Relation between popping expansions and dry weight per kernel from butt, center, and tip sections, and from entire ears of Purdue 202 (averages of 25 ears, 1955). (Fig. 12)

Assuming that a popping expansion of 30 volumes is the trade standard, the tip, center, and butt sections of Iopop 6 harvested in 1955 reached 30 volumes with dry weights per kernel of 69.3, 82.5, and 94.0 mg. respectively. For the entire ear this point coincided with 80 mg. The maximum popping expansion for the tip sections was 35 volumes, but the center and butt sections attained 37 volumes.

Purdue 202 showed a similar but more pronounced relationship (Fig. 12). At 118.0 mg. dry weight per kernel for the entire ear, the popping expansion reached 30 volumes. When the tip, center, and butt sections reached a popping expansion of 30 volumes, the dry weights per kernel were 114.8, 123.5, and 131.9 mg. respectively. The maximum expansions for the three ear sections were 36, 40, and 38 volumes for the tip, center, and butt sections respectively, and 40 volumes for the entire ear.

Both the average dry weights per kernel by ear section and the corresponding popping expansion of Iopop 6 (Table 8) decrease from butt, through center, to the tip. The kernel dry weights of Purdue 202 showed the same trend, but only the tip sections had a decreased popping expansion.

The maturity experiments were again repeated in 1956 (Tables 18 and 19), but with certain variations. In the first series, which matured normally (Table 18), the harvests of Iopop 6 and Purdue 202 began at 35.3- and 36.1-percent kernel moisture respectively. The dry weight per kernel of Iopop 6 changed very little after reaching 32.9-percent harvest moisture. In Purdue 202 there was no trend below 31.5-percent kernel moisture.

The harvests from a second planting in 1956 (Table 19) were started at a much higher moisture level; and since it was impossible to remove the kernels from the early harvested ears, only the ear moistures were recorded. After room drying, the ears were shelled and the kernels weighed and counted. The dry weights per kernel increased very rapidly during the early harvest stages (74.4- to 39.8-percent ear moisture). After reaching 29.5-percent kernel moisture, the dry weights per kernel of Iopop 6 changed very little and failed to develop as great a dry weight as in the first series (Table 18) by a considerable margin.

The trends in Purdue 202 (Table 19) were practically the same as those for Iopop 6 except that the dry weights per kernel were much below those in Table 18. This decrease may be attributed to the month-long drouth (Tables 2 and 3) which prevented normal kernel development. Purdue 202 was planted higher in a sloping field than Iopop 6, and consequently was more severely damaged by drouth than the latter. The Purdue 202 corn was also badly infected with European corn borer.

Table 18. — Relation Between Moisture at Harvest, Dry Weight, and Popping Expansion of Iopop 6 and Purdue 202 Dried at Room Temperature, 1956[a]

Iopop 6					Purdue 202				
Kernels		Cobs			Kernels		Cobs		
Percent moisture at harvest	Dry weight per kernel (mg.)	Percent moisture at harvest	Dry weight per cob (gm.)	Popping expansion (volumes)[b]	Percent moisture at harvest	Dry weight per kernel (mg.)	Percent moisture at harvest	Dry weight per cob (gm.)	Popping expansion (volumes)[b]
35.3	95.0	51.9		36.8	36.1	139.2	47.7		36.3
33.2	96.9	50.8	15.0	34.6	32.6	138.0	46.7		37.2
32.9	101.0	48.7		37.2	31.5	144.3	46.8	19.2	36.3
32.6	95.6	50.4	14.2	35.0	29.4	139.1	43.5	19.8	36.8
27.8	98.3	45.4	13.1	35.5	28.3	145.8	42.9	20.6	36.3
26.2	104.3	46.9	16.1	36.3	24.1	138.8	39.7	19.5	35.5
23.8	98.1	47.5	13.3	37.2	21.5	142.3	33.1	20.3	35.5
20.3	97.7	31.8	12.7	35.9	18.0	141.1	23.5	20.1	37.2
20.2	102.6	29.2	13.7	37.2	17.5	141.8	25.2	20.0	38.5
17.7	102.2	28.9	15.0	36.8	16.8	145.3	22.3	17.5	37.6
17.1	107.4	26.1	14.9	36.8	15.4	144.8	19.6	21.1	37.2
16.8	101.5	23.7	15.0	35.9	14.0	142.8	15.8	20.5	37.6
14.0	99.9	17.2	15.9	36.3	13.7	141.5	15.8	19.5	37.6
12.1	102.0	13.2	15.0	36.8	13.0	143.5	13.4	20.6	37.6
10.1	104.1	9.7	13.7	37.2	10.2	142.4	9.7	21.2	38.0
Average	100.4 ± .91[c]		14.4 ± 2.8	36.5 ± .17[c]		142.4 ± .64[c]		20.0 ± .26	37.1 ± .26[c]

[a] Early planting that escaped most of the severe shortage of soil moisture. Harvest started September 14 and ended October 17.
[b] All samples were reconstituted with water to 12.5-percent kernel moisture.
[c] Below about 30-percent kernel moisture.

Table 19. — Relation Between Moisture at Harvest, Dry Weight, and Popping Expansion of Iopop 6 and Purdue 202 Dried at Room Temperature, 1956[a]

Iopop 6						Purdue 202					
Percent moisture at harvest		Dry weight per kernel (mg.)	Cobs		Popping expansion (volumes)	Percent moisture at harvest		Dry weight per kernel (mg.)	Cobs		Popping expansion (volumes)[b]
Entire ear	Kernels		Percent moisture at harvest	Dry weight per cob (gm.)		Entire ear	Kernels		Percent moisture at harvest	Dry weight per cob (gm.)	
74.4	....	10.4	....	11.8	....	69.8	....	23.4	....	16.4	....
70.6	....	17.1	....	11.7	....	66.7	....	31.0	....	16.2	....
67.7	....	22.0	....	12.7	....	66.1	....	36.4	....	16.0	....
63.5	....	26.5	....	11.8	....	62.0	....	45.9	....	15.4	....
59.6	....	34.1	....	11.5	....	57.0	....	57.1	....	13.9	....
51.6	....	40.9	....	10.9	5.5	52.2	....	65.2	....	14.7	5.5
49.6	....	50.3	....	11.2	7.5	49.8	....	77.7	....	14.9	8.5
46.6	....	55.7	....	12.1	12.5	49.7	....	88.2	....	16.7	15.0
45.0	....	67.5	....	12.7	18.3	42.3	....	100.6	....	16.5	23.3
41.1	....	74.3	....	12.8	23.0	41.7	....	102.0	....	17.0	19.5
41.0	....	76.4	....	12.5	27.0	39.0	....	89.1	....	15.5	23.0
39.8	....	75.5	....	12.1	26.5	34.5	....	101.4	....	16.1	23.0
Average				12.0 ± .17						15.8 ± .26	
....	32.4	80.5	53.2	11.9	32.5	....	26.8	96.9	43.3	16.6	29.9
....	29.5	91.5	48.5	15.7	38.0	....	25.4	101.6	36.4	18.6	34.2
....	29.1	86.1	45.6	13.8	36.8	....	22.8	104.7	35.1	17.3	33.4
....	27.6	91.0	44.0	13.5	37.6	....	18.5	95.8	23.9	16.4	32.9
....	23.8	89.9	36.1	13.5	38.5	....	17.0	101.9	19.8	17.7	31.6
....	23.8	87.8	39.3	13.8	38.0	....	15.2	103.1	17.2	18.1	33.8
....	20.7	94.8	32.5	13.9	37.2	....	13.6	102.8	14.3	16.4	34.6
....	20.5	92.9	32.0	15.1	36.8	....	12.2	101.2	10.0	17.1	34.2
....	18.0	94.1	24.7	14.4	38.0	....	12.2	102.2	10.2	16.4	32.9
....	13.8	92.5	15.0	13.4	36.8	....	11.4	101.2	10.6	17.9	34.2
....	12.1	90.7	12.6	14.5	37.6	....	10.4	99.8	9.7	16.1	34.6
Average		90.2 ± 1.24		13.9 ± .30	37.5 ± .20			101.0 ± .79		17.1 ± .24	33.3 ± .34

[a] Late planting that ripened prematurely because of the severe shortage of soil moisture. Harvests from August 27 to September 21 are indicated by entire ear moistures. Subsequent harvests (September 24 to October 17) are represented by kernel moistures.
[b] All samples were reconstituted with water to 12.5-percent kernel moisture.

The dry weights per cob in Iopop 6 and Purdue 202 did not change materially through the entire range of ear and kernel moistures (Tables 18 and 19). Allowing for the normal variations in size of cob, the average dry weight per cob of Iopop 6 above 39.8-percent ear moisture was 12.0 gm. as compared with 13.9 gm. between 32.4- and 12.1-percent kernel moisture. Similar comparisons of Purdue 202 showed an average of 15.8 gm. per cob above 34.5-percent ear moisture and 17.1 gm. between 26.8- and 10.4-percent kernel moistures (Table 19). These slight differences indicate that the cobs were fully mature much earlier than the kernels.

FACTORS AFFECTING ENDOSPERM FRACTURING

Bemis and Huelsen (2) found that, as indicated by highly significant correlation coefficients, the rate of moisture loss from the kernels during drying by artificial heat was closely related to the number of kernels having fractured endosperms; but the final moisture content was not a factor. In Iopop 6 the harvest moisture and fracturing were positively and significantly correlated, but in Purdue 202 there was only a very small negative correlation.

The 1955 experiments afforded an excellent opportunity to gain further information on endosperm fracturing, since the records were kept by ear section and the ears were dried at room temperature as well as by heat at 110° F. Both the room-dried and artificially dried ears were not sectioned until just before the counts were made.

The fracture counts were made on duplicate 100-kernel samples, and the results in Table 20 are expressed in terms of the number of kernels with fractured endosperms per 100 total kernels. Virtually no fracturing occurred when the corn was dried slowly at room temperatures. As indicated by the dry weights in Table 20, the butt sections of the two hybrids had the largest kernels. These kernels were subject to the greatest amount of fracturing. The center and tip sections of Iopop 6 averaged about the same number of kernels fractured, but the tip sections of Purdue 202 had more fractured kernels than the center sections.

When the corn was dried at 110° F., fracturing of the kernels from the butt sections of Iopop 6 decreased in relation to the initial moisture. Since kernels with a high initial moisture content dry much more rapidly than those with a low initial moisture content, the decreased rate of moisture loss in the dryer was accompanied by a decrease in fracturing. The butt and center sections of Purdue 202 showed the same trends and had similar drying rates. All the lots were dried from 45 to 48

Table 20. — Endosperm Fracturing of Iopop 6 and Purdue 202 Kernels Dried at Room Temperatures and at 110° F.

(Average number of kernels showing fractures in two 100-kernel samples, 1955)

Iopop 6								Purdue 202							
Percent moisture at harvest[a]	Room-dried			Dried at 110° F.				Percent moisture at harvest[a]	Room-dried			Dried at 110° F.			
	Butt	Center	Tip	Butt	Center	Tip	Percent moisture loss per hour		Butt	Center	Tip	Butt	Center	Tip	Percent moisture loss per hour
44.2	6.0	0	0					44.8	6.5	2.5	.5				
43.8	1.0	0	0					43.8	1.0	0	1.0				
41.0	3.5	0	0					40.4	3.5	0	.5				
36.6	.5	0	0					36.6	0	0	0				
34.6	0	0	0	40.0	10.0	5.0	.47	34.8	0	0	0	46.5	30.0	30.5	.45
33.8	0	0	0	45.0	11.5	7.5	.43	34.8	0	0	0	52.0	38.0	17.0	.43
32.4	0	0	0	46.5	6.0	6.0	.41	31.2	0	0	0	53.5	29.5	36.0	.42
32.0	0	0	0	33.0	5.5	3.5	.43	30.8	0	0	0	35.5	13.5	16.5	.38
31.8	0	0	0	42.5	9.5	8.5	.40	29.6	0	0	0	52.0	27.5	39.0	.40
30.0	0	0	0	51.0	9.5	9.0	.43	28.2	0	0	0	48.0	27.0	37.5	.34
27.8	0	0	0	41.0	3.5	6.0	.32	27.6	0	0	0	36.0	16.5	22.0	.34
26.4	0	0	0	42.0	17.0	13.0	.38	26.8	0	0	0	44.8	21.5	37.5	.36
26.2	0	0	0	42.0	7.0	12.0	.43	25.0	0	0	0	35.0	20.5	30.0	.37
25.0	0	0	0	25.0	2.5	3.5	.26	24.0	0	0	0	39.0	25.5	29.0	.28
23.0	0	0	0	43.0	14.5	20.0	.31	23.6	0	0	2.5	34.5	22.0	34.5	.34
22.6	0	0	1.5	25.0	3.5	10.5	.33	22.0	0	0	2.0	33.0	16.0	27.5	.31
21.0	0	0	0	31.5	4.5	13.5	.27	20.4	0	0	0	26.0	15.0	41.0	.27
21.0	0	0	0	27.0	7.5	11.0	.27	20.2	0	0	2.0	15.0	4.0	47.5	.27
20.4	0	0	0	31.0	5.0	8.5	.30	19.0	0	0	0	24.0	16.0	35.0	.26
19.4	0	0	5.0	22.5	2.0	5.5	.26	18.6	0	0	2.0	15.0	6.5	26.0	.23
19.0	0	0	1.5	26.5	4.5	6.5	.20	18.2	0	0	3.5	23.0	15.5	29.5	.17
18.4	0	0	0	21.0	5.0	5.5	.26	17.6	0	0	5.0	14.5	3.0	26.0	.25
18.4	0	0	0	20.0	3.5	4.5	.29	16.6	0	0	12.5	19.5	9.5	27.5	.24
17.0	0	0	0	41.0[b]	15.0[b]	12.5[b]	.24	16.4	0	0	0	42.5[b]	20.0[b]	57.0[b]	.20
Average fracturing				34.8	7.4	8.6						34.5	18.8	32.3	
Average dry weight per kernel (mg.)				106.6	95.8	79.1						150.4	142.0	122.2	

[a] Kernel moisture of whole ear.
[b] Freeze on November 3 (minimum temperature 24°, maximum 30° F.), following 1.35 inches of rain November 1, 2, and 3.

hours at 110° F., and it is probable that the decreased fracturing was due to the lower kernel moisture at harvest rather than to the decreased drying rate per hour. Since the more mature lots contained a lower initial moisture, the drying rate per hour was naturally less. Drying did not proceed at a uniform rate. Lots with a high initial moisture content, as shown by Huelsen and Bemis (13), lost moisture rapidly upon first entering the dryer. The drying rate slowed down rapidly as the moisture content of the ears decreased.

The popping expansions of the respective ear sections of Purdue 202 are shown in Fig. 10. When dried at room temperatures, the kernels from the tip sections of both hybrids did not pop as well as those from the center and butt sections. A similar tendency was noted in the artificially dried lots, with Purdue 202 showing a greater difference than Iopop 6. Since the two methods of drying had similar trends, it is doubtful whether increased fracturing was responsible for the lower popping expansion of the tip sections.

As indicated in Fig. 10, the artificially dried ears did not pop quite as well as the room-dried ears, but it is doubtful that endosperm fracturing was responsible for the difference. Practically all of the lots were dried to moistures below the 12.5 percent optimum for popping. These lots were reconstituted with water. Bemis and Huelsen (2) showed that rehydration of kernels with perfect endosperms results in considerable fracturing even when the increases in moisture content are small.

SUMMARY AND CONCLUSIONS

Maturity studies were conducted with two popcorn hybrids, Iopop 6 and Purdue 202, over a three-year period, 1954-1956. Two plantings of the hybrids were made each year. Samples of at least five ears, except as noted, were harvested three times weekly as part of a much larger sample used for popping. The ears were shelled together and the cobs combined into one sample in order to determine the moisture content. In 1955 the ears were tested individually after division into three nearly equal sections.

All samples were dried either at room temperatures or at 110° F. Later they were reconstituted with water to 12.5-percent moisture and popped. In 1956 corn was permitted to stand in the field until December 26, long after it had dried sufficiently for cribbing. Two control series were stored in outdoor cribs.

Kernel and cob moistures were equal in both hybrids at about 50-percent moisture. The kernel moistures decreased rapidly, but the cob moistures remained static until the kernel moistures reached about 30

percent. After that point, both the kernel and cob moistures dropped rapidly, tending to reach equilibrium again in the field when the moisture content fell to about 15 percent or slightly lower. During the fall of 1956, corn standing in the field and held in outdoor cribs after harvesting reached a low point of about 10-percent kernel and cob moisture. By December 26 the kernels and cobs of both hybrids had absorbed about 7 percent additional moisture from rain and ground fogs.

It is unusual, however, for popcorn to reach 10-percent moisture content in the field. Under ordinary conditions popcorn should be harvested as early as possible, consistent with keeping qualities in the corn crib. Long exposures under field conditions are not recommended; and since popcorn in the crib absorbed moisture at the same rate as that standing in the field, the question may be raised whether it is advisable to store popcorn for long periods in ordinary outdoor corn cribs.

The three-year period covered by the experiments included one of the driest fall seasons on record as well as one that was warm and unusually rainy. There was no evidence that rainfall caused an increase in the kernel and cob moisture during the normal maturity period of September and October, even though the stalks were either definitely dying or entirely dead. However, the average daily moisture loss from kernels and cobs was most rapid during the driest fall and slowest during the wettest. During the wettest fall, even though October temperatures were far above normal, almost twice as much time was required for the popcorn to lose an equivalent percentage of moisture as during the driest fall.

Under favorable conditions Iopop 6 develops a considerable percentage of second or lower ears on the stalks. Comparison of the drying rates showed that upper and lower ears contained the same amount of moisture at the 45-percent kernel moisture stage; but as maturity advanced, the upper ears dried slightly faster than the lower ears until within the 35- to 30-percent stage. After that point, maturity proceeded at the same rate. In contrast, the cobs from the lower ears lost moisture at a slower rate than the cobs from the upper ears, but below 20-percent kernel moisture the differences were small.

Kernel-cob moisture relationships are important from a practical standpoint because of their effect on shelling percentages. Popcorn is often purchased from the grower at 20-percent kernel moisture, and it is important to know what cob moisture to expect at this time. Moisture tests covering the five-year period 1952-1956 showed that when the kernel moisture reached 20 percent the cobs of Iopop 6 contained 8.5 to 15 percent more moisture than the kernels and those of Purdue 202 from 9 to 13 percent more.

Although previous work indicated that rapid drying of popcorn by artificial heat was somehow injurious to popping expansion, these experiments revealed that below 25-percent kernel moisture the injurious effects were slight. Drying experiments showed that the kernels dried much faster than the cobs at 110° F. The theory was advanced that the several sections of the ear might differ in moisture content. Although the kernel moisture of the entire ear might average 25 percent, one part of the ear could have a higher initial moisture content than another, and therefore the average popping expansion for that part could possibly be damaged when dried at 110° F.

Successive harvests three times weekly indicated, however, that the kernels shelled from butt, center, and tip sections of Iopop 6 and Purdue 202 all lost moisture at practically the same rate. There were slight differences in the drying rates of the ear sections and between varieties, but these were too small to account for any variations in popping expansion.

The cob sections, in contrast, showed considerable differences in moisture content at harvest. The tip sections of the cobs of both upper and lower ears of Iopop 6 contained less moisture at all stages below 50- to 47-percent butt moisture. Above 30-percent butt moisture, the center cob sections of the upper ears of Iopop 6 also contained consistently less moisture than the butt sections. The relationship was similar in the lower ears. In Purdue 202 the tip cob sections contained less moisture than the butts at all stages. The butt and center sections contained approximately the same amount of moisture below about 35-percent butt moisture. In general, the butt sections of the cobs of both hybrids contained more moisture at harvest than the center and tip sections.

Under drying conditions in an unheated attic, both the kernels and cobs of the butt and tip sections of the two hybrids lost moisture at a more rapid rate than the center sections, indicating a gradual transfer of moisture from the center toward the ends of the ears. Almost without exception, the kernels and cobs of the center sections contained more moisture than either end of the ear at the close of the drying period. Throughout the entire room-drying period, the tip sections of the cobs of both hybrids contained slightly less moisture than the butt sections. The center sections, on the other hand, contained less moisture than either the butts or tips below 35-percent butt moisture. Above 36- to 40-percent butt moisture, the center sections contained more moisture than either butt or tip sections.

Shelling percentages were affected to a considerable extent by the moisture content (maturity) at harvest. Iopop 6 and Purdue 202 were

harvested periodically at three initial kernel-moisture levels — 44 to 45, 30 to 33, and 19 to 21 percent — and dried at room temperatures. Both the actual and adjusted (to 13-percent moisture) shelling percentages were reduced in the earliest harvest, but the two later harvests had comparable shelling percentages.

Since the kernel-cob moisture relationships below 35-percent kernel moisture appeared to be fairly constant, a table was compiled to show the expected shelling percentages on both an unadjusted and adjusted (to 13-percent moisture content) basis for the 33- to 12-percent kernel-moisture range. The calculated table was found to check closely with the actual shelling percentages obtained over a two-year period.

It is sometimes assumed that the lower ears of a multiple-eared hybrid like Iopop 6 will have a smaller shelling percentage than the upper ears, especially since the lower ears often weigh less than the upper ears. On an unadjusted moisture basis, the shelling percentages of the lower ears were slightly higher than those of the upper ears. When adjusted to 13-percent kernel moisture, however, the lower ears tended to have the same or a very slightly higher shelling percentage than the upper ears.

In dent corn the kernel-cob moisture relationships for ears taken directly from the field differ from those for ears taken from outdoor corn cribs; consequently the shelling percentages of the two also differ. But the moisture relationships between kernels and cobs of popcorn ears taken from the field were identical with those for ears removed at the same time from outdoor cribs. Their shelling percentages were also similar.

Popping expansion is conditioned by variety and by moisture content at the time of popping. Morphological and physiological development, collectively termed "maturity," is also important, but practically nothing is known about its effect on popping expansion.

Preliminary work in 1954 showed that the kernels reached maximum popping expansion between 35- and 30-percent kernel moisture, after which there was a slight decrease in expansion. The experiments were repeated in 1955 with similar results, except that the maximum popping expansion fell within the 30- to 25-percent kernel-moisture range. The ears were divided into three sections; in general, the center sections popped the best and the tip sections the poorest. The experiments were repeated again in 1956; but owing to prolonged drouth, there were no trends in popping expansion below 35-percent kernel moisture. The results of these experiments over the three-year period

showed clearly that harvesting at 30-percent moisture had no adverse effects on popping expansion when the ears were slowly dried at room temperature. However, the subsequent decline in popping expansion in later harvests could not be explained.

Very similar trends were observed when popcorn was dried by forced hot air at 110° F. The exception was that harvest had to be delayed until the kernel moisture reached 25 percent. The popping expansions of corn handled in four different ways were compared. Corn harvested from the field, taken from outdoor corn cribs, or dried at room temperature popped about the same; but corn dried at 110° F. had a slightly lower popping expansion.

Iopop 6 and Purdue 202 were harvested at four different times with kernel moistures as high as 28 percent. The ears were husked and stored at two temperatures, 25° F. and −40° F. The results were variable, but none of the cold treatments reduced popping expansion sufficiently to make the corn unmarketable.

This experiment was supplemented by another in which the popping expansions of corn stored in outdoor cribs were compared weekly with those for corn remaining on the stalk in the field. This experiment was terminated December 26. Despite low temperatures, the ears in the field popped as well as those in the cribs.

It was then believed that weathering (alternate wetting and drying) rather than low temperatures alone might be responsible for damage to popping expansion, and two lots were artificially weathered to test this hypothesis. The ears were soaked up to two hours, held while wet at 35° F. for 24 hours, and then dried by unheated forced air. Five or six of these cycles were required before any serious effects were noted, indicating that Iopop 6 and Purdue 202 are well able to resist weathering.

Underdeveloped ears, as indicated by abnormally low dry weights per kernel, had an adverse effect on popping expansion. Underdevelopment may be caused by prolonged drouth, disease, insect damage, or mechanical injury.

Dry weights, or moisture-free weights, are an index of kernel development. These will vary from season to season and from one field to the next, and when they are too low, popping expansion suffers. The three years of experiments showed that maximum kernel dry weights coincided very closely with 30-percent kernel moisture. Below 30 percent there was a distinct tendency for the dry weights per kernel to decrease, a trend that could not be explained. Butt, center, and tip sections all showed practically the same trends. The dry weights of the

kernels from the butt sections were higher than those from the tip sections, reflecting the differences in sizes of the kernels.

Dry weights per kernel and popping expansion were significantly correlated above 34-percent kernel moisture when the ears were dried at room temperatures, but at lower moistures the coefficients were not significant. When analyzed on the basis of ear section, considerable differences were noted in the dry weights when the kernels reached the trade standard of 30 volumes expansion. Tip, center, and butt sections reached 30 volumes in the order given, the tip sections weighing much less than either center or butt sections. However, the maximum popping expansions of the tip sections were less than those of either the center or butt sections.

In 1956 harvests were started when the ear moisture reached 74 to 70 percent. Dry weights per kernel increased very rapidly as maturity advanced and remained static after the kernel moisture reached approximately 30 percent, proving again that the point where full maturity is reached comes much earlier than is generally believed.

The cobs reached full maturity as indicated by their constant dry weights at above 70-percent moisture. At this time the kernels had the same or slightly less moisture, but were losing moisture rapidly. The cobs, on the other hand, maintained a fairly constant moisture content. By the time the kernels reached 35- to 30-percent moisture, the cobs also started to lose moisture rapidly, but without any increase in dry weight.

Further experiments on endosperm fracturing indicated that practically no fracturing occurred when the husked ears were dried in an unheated room. The percentage of kernel moisture at harvest was not a factor. Drying the ears at 110° F. was the cause of severe fracturing. Comparing the amount of fracturing by ear section showed that fracturing increased in relation to kernel dry weight. In other words, more kernels from butt sections fractured than tip kernels. Center sections were intermediate. Fracturing of the kernels from the butt sections of Iopop 6 and from the butt and center sections of Purdue 202 decreased as maturity advanced. The center and tip sections of Iopop 6 and the tip sections of Purdue 202 failed to show a similar trend.

Fracturing was confined to the ears dried at 110° F.; and since these popped slightly less than the controls dried at room temperature, it might be assumed that the decrease in popping was due to fracturing. However, evidence proved that this conclusion was erroneous.

LITERATURE CITED

1. Anderson, E., and Cutler, H. C. Races of *Zea Mays:* I. Their Recognition and classification. Mo. Bot. Gard. Ann. **29**, 69-86. 1942.
2. Bemis, W. P., and Huelsen, W. A. Dehydration and rehydration in relation to endosperm fracturing of popcorn. Am. Soc. Hort. Sci. Proc. **65**, 371-380. 1955.
3. Bemis, W. P., and Huelsen, W. A. Estimating the shelling percentage of Iopop 6 and Purdue 202 popcorn. Popcorn Merchandiser **10**(3), 30-33. 1955.
4. Bemis, W. P., and Huelsen, W. A. Maturity in relation to popping expansion of popcorn. Amer. Soc. Hort. Sci. Proc. **67**, 451-459. 1956.
5. Brunson, A. M., and Smith, G. M. Popcorn. U. S. Dept. Agr. Farmers' Bul. 1679. 1948.
6. Eldredge, J. C., and Thomas, W. I. Popcorn experiments for 1953. Iowa Agr. Exp. Sta. Mimeo. n.d.
7. Eldredge, J. C. Factors affecting popping volume. Iowa Agr. Exp. Sta. Mimeo. 1953.
8. Eldredge, J. C. Factors affecting popping volume. Popcorn Merchandiser **9**(1), 20-33. 1954.
9. Eldredge, J. C., and Thomas, W. I. Popcorn experiments for 1954. Iowa Agr. Exp. Sta. Mimeo. n.d.
10. Eldredge, J. C., and Thomas, W. I. Popcorn experiments for 1955. Iowa Agr. Exp. Sta. Mimeo. n.d.
11. Huelsen, W. A., and Thompson, A. E. Artificial drying of popcorn in relation to popping expansion. Amer. Soc. Hort. Sci. Proc. **60**, 341-350. 1952.
12. Huelsen, W. A., and Bemis, W. P. Reconstituting moisture in overdried popcorn by blending with wet popcorn. Food Technol. **9**, 426-430. 1955.
13. Huelsen, W. A., and Bemis, W. P. Artificial drying and rehydration of popcorn and their effects on popping expansion. Ill. Agr. Exp. Sta. Bul. 593. 1955.
14. Kiesselbach, T. A. The structure and reproduction of corn. Neb. Agr. Exp. Sta. Res. Bul. 161. 1949.
15. Kiesselbach, T. A. Progressive development and seasonal variations of the corn crop. Neb. Agr. Exp. Sta. Res. Bul. 166. 1950.
16. Miles, S. R., and Remmenga, E. E. Relations of kernel, cob, and ear moisture in dent corn. Purdue (Ind.) Agr. Exp. Sta. Bul. 599. 1953.
17. Randolph, L. F. Developmental morphology of the caryopsis in maize. Jour. Agr. Res. **53**, 881-916. 1936.

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